This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at http://books.google.com/

NYPL RESEARCH LIBRARIES
3 3433 06905553 5

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

PROCEEDINGS
OF
THE INSTITUTE OF RADIO ENGINEERS
(INCORPORATED)

VOLUME 5

1917

EDITED BY

ALFRED N. GOLDSMITH, Ph.D.

PUBLISHED EVERY TWO MONTHS BY

THE INSTITUTE OF RADIO ENGINEERS
(INC.)

ONE HUNDRED AND ELEVEN BROADWAY
NEW YORK

Digitized by Google

THE NEW YORK
PUBLIC LIBRARY
123242B
ASTOR, LENOX AND
TILDEN FOUNDATIONS
R 1941 L

GENERAL INFORMATION

The right to reprint limited portions or abstracts of the articles, discussions, or editorial notes in the PROCEEDINGS is granted on the express condition that specific reference shall be made to the source of such material. Diagrams and photographs in the PROCEEDINGS may not be reproduced without securing permission to do so from the Institute thru the Editor.

Those desiring to present original papers before The Institute of Radio Engineers are invited to submit their manuscript to the Editor.

Manuscripts and letters bearing on the PROCEEDINGS should be sent to Alfred N. Goldsmith, Editor of Publications, The College of The City of New York, New York.

Requests for additional copies of the PROCEEDINGS and communications dealing with Institute matters in general should be addressed to the Secretary, The Institute of Radio Engineers, 111 Broadway, New York.

The PROCEEDINGS of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings in New York, Washington, Boston or Seattle.

Payment of the annual dues by a member entitles him to one copy of each number of the PROCEEDINGS issued during the period of his membership. Members may purchase, when available, copies of the PROCEEDINGS issued prior to their election at 75 cents each.

Subscriptions to the PROCEEDINGS are received from non-members at the rate of $1.00 per copy or $6.00 per year. To foreign countries the rates are $1.10 per copy or $6.60 per year. A discount of 25 per cent is allowed to libraries and booksellers. The English distributing agency is "The Electrician Printing and Publishing Company," Fleet Street, London, E. C.

Members presenting papers before the Institute are entitled to ten copies of the paper and of the discussion. Arrangements for the purchase of reprints of separate papers can be made thru the Editor.

It is understood that the statements and opinions given in the PROCEEDINGS are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

COPYRIGHT, 1917, BY
THE INSTITUTE OF RADIO ENGINEERS, INC.
ONE HUNDRED AND ELEVEN, BROADWAY
NEW YORK, N. Y.

Digitized by Google

CONTENTS OF VOLUME 5

1917

NUMBER 1; February, 1917

NUMBER 2; April, 1917

NUMBER 3; June, 1917

Digitized by Google

NUMBER 4; August, 1917

NUMBER 5; October, 1917

NUMBER 6; December, 1917

Digitized by Google

VOLUME 5 FEBRUARY 1917 NUMBER 1

PROCEEDINGS

of

The Institute of Radio Engineers

(INCORPORATED)

TABLE OF CONTENTS

PROCEEDINGS OF THE SECTIONS

TECHNICAL PAPERS AND DISCUSSIONS

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

PUBLISHED EVERY TWO MONTHS BY
THE INSTITUTE OF RADIO ENGINEERS, INC
ONE HUNDRED AND ELEVEN BROADWAY
NEW YORK

THE TABLE OF CONTENTS FOLLOWS ON PAGE 3

Digitized by Google

GENERAL INFORMATION

The right to reprint limited portions or abstracts of the articles, discussions, or editorial notes in the Proceedings is granted on the express condition that specific reference shall be made to the source of such material. Diagrams and photographs in the Proceedings may not be reproduced without securing permission to do so from the Institute thru the Editor.

Those desiring to present original papers before The Institute of Radio Engineers are invited to submit their manuscript to the Editor.

Manuscripts and letters bearing on the Proceedings should be sent to Alfred N. Goldsmith, Editor of Publications, The College of the City of New York, New York.

Requests for additional copies of the Proceedings and communications dealing with Institute matters in general should be addressed to the Secretary, The Institute of Radio Engineers, 111 Broadway, New York.

The Proceedings of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings in New York, Washington, Boston, Seattle, or San Francisco.

Payment of the annual dues by a member entitles him to one copy of each number of the Proceedings issued during the period of his membership. Members may purchase, when available, copies of the Proceedings issued prior to their election at 75 cents each.

Subscriptions to the Proceedings are received from non-members at the rate of $1.00 per copy or $6.00 per year. To foreign countries the rates are $1.10 per copy or $6.60 per year. A discount of 25 per cent. is allowed to libraries and booksellers. The English distributing agency is "The Electrician Printing and Publishing Company," Fleet Street, London, E. C.

Members presenting papers before the Institute are entitled to ten copies of the paper and of the discussion. Arrangements for the purchase of reprints of separate papers can be made thru the Editor.

It is understood that the statements and opinions given in the Proceedings are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

COPYRIGHT, 1917, BY
THE INSTITUTE OF RADIO ENGINEERS, INC.

ONE HUNDRED AND ELEVEN BROADWAY
NEW YORK, N. Y.

Digitized by Google

CONTENTS

Digitized by Google

OFFICERS AND BOARD OF DIRECTION, 1917

(Terms expire January 2, 1918; except as otherwise noted.)

PRESIDENT
MICHAEL I. PUPIN

VICE-PRESIDENT
JOHN L. HOGAN, JR.

TREASURER
LOUIS R. KRUMM

SECRETARY
DAVID SARNOFF

EDITOR OF PUBLICATIONS
ALFRED N. GOLDSMITH

MANAGERS

(Serving until January 7, 1920)

ERNST F. W. ALEXANDERSON
JOHN STONE STONE

(Serving until January 1, 1919)

EDWIN H. ARMSTRONG
GEORGE S. DAVIS

(Serving until January 2, 1918)

LOUIS W. AUSTIN
JOHN HAYS HAMMOND, JR.
LLOYD ESPENSCHIED
JOHN STONE STONE
ROY A. WEAGANT

ADVERTISING MANAGER
LOUIS G. PACENT

WASHINGTON SECTION

EXECUTIVE COMMITTEE

CHAIRMAN
LIEUT.-COLONEL GEORGE O. SQUIER
War Department,
Washington, D. C.

SECRETARY-TREASURER
GEORGE H. CLARK
Navy Department,
Washington, D. C.

CHARLES J. PANNILL
Radio, Va.

BOSTON SECTION

CHAIRMAN
A. E. KENNELLY,
Harvard University,
Cambridge, Mass.

SECRETARY-TREASURER
MELVILLE EASTHAM,
11 Windsor Street,
Cambridge, Mass.

SEATTLE SECTION

CHAIRMAN
ROBERT H. MARRIOTT,
715 Fourth Street,
Bremerton, Wash.

SECRETARY-TREASURER
TYNG M. LIBBY,
1337 Warren Avenue,
Bremerton, Wash.

Digitized by Google

SAN FRANCISCO SECTION

CHAIRMAN	SECRETARY-TREASURER
W. W. Hanscom, 848 Clayton Street, San Francisco, Cal.	V. Ford Greaves, 526 Custom House, San Francisco, Cal.

H. G. Aylsworth
145 New Montgomery Street,
San Francisco, Cal.

PAST-PRESIDENTS

SOCIETY OF WIRELESS TELEGRAPH ENGINEERS

John Stone, Stone, 1907–8
Lee De Forest, 1909–10
Fritz Lowenstein, 1911–12

THE WIRELESS INSTITUTE

Robert H. Marriott, 1909–10–11–12

THE INSTITUTE OF RADIO ENGINEERS

Robert H. Marriott, 1912
Greenleaf W. Pickard, 1913
Louis W. Austin, 1914
John Stone Stone, 1915
Arthur E. Kennelly, 1916

The Membership of the Standing Committees of The Institute for 1917 will be announced in an early issue of The Proceedings of The Institute of Radio Engineers.

Digitized by Google

PROCEEDINGS OF THE SECTIONS

WASHINGTON SECTION

A meeting of the Washington Section of The Institute of Radio Engineers was held at the University Club, Washington, on the evening of Monday, November 27, 1916. Prior to the meeting, a dinner was given in honor of the retiring Chairman of the Section, Colonel Samuel Reber, U. S. A. There were thirty-two members present. In the course of the meeting, Lieutenant-Colonel George O. Squier, U. S. A., was elected Chairman for 1917, and the remaining members of the Executive Committee of the Washington Section were re-elected.

BOSTON SECTION

On the evening of Thursday, November 2, 1916, a meeting of the Boston Section was held in the Cruft High Tension Laboratory, Harvard University. Professor A. E. Kennelly, President of the Institute, presented a paper on "Telephone Receivers" illustrated by lantern slides.

On the evening of Thursday, December 14, 1916, a meeting of the Boston Section was held at the Cruft High Tension Laboratory. Mr. H. J. W. Fay presented an illustrated paper on "Submarine Signaling."

SEATTLE SECTION

On the evening of September 9, 1916, a meeting of the Seattle Section of the Institute was held in Seattle. A paper by Mr. Robert H. Marriott, Past-President of the Institute, on "Radio Shadows" was presented. The attendance was ten. Certain financial arrangements were carried out on the same occasion.

SAN FRANCISCO SECTION

A meeting of the San Francisco Section of the Institute was held at the Engineers' Club, Mechanics Institute Building, San Francisco, on the evening of November 21, 1916; Mr. W. W. Hanscom presiding. A paper on "The Proposed Navy Bill and Government Ownership of Radio Stations" was presented by Mr. George S. de Sousa. There were twenty-nine members present. Following the paper, Messrs. Hanscom and Greaves gave discussions thereon. Matters dealing with the further organization of the San Francisco Section were then considered by the meeting.

A dinner and meeting of the San Francisco Section were held on the evening of December 19, 1916, at the Engineers' Club,

Digitized by Google

San Francisco, Mr. W. W. Hanscom presiding. At the dinner the attendance was twenty, and at the meeting following the attendance was forty-nine. Two papers were presented at the meeting. The first of these, by Mr. Oscar C. Roos, was on "Radio Conditions in the Philippine Islands." The second, by Mr. Ellery W. Stone, dealt with "Additional Experiments with Impulse Excitation." The first paper was discussed by Messrs. Hanscom and Greaves, and the second by Messrs. Pratt, F. C. Ryan, and the Author. Local organization and financial matters were further considered at the meeting.

Digitized by Google

ENGINEERING PRECAUTIONS IN RADIO INSTALLATIONS*

By

Robert H. Marriott

(Expert Radio Aid, Navy Yard, Bremerton, Washington)

Probably all devices used to produce some desirable result may, under certain conditions, produce or contribute to the production of undesirable results, or damage. The probability of damage from radio apparatus compares favorably with that from other useful devices, and is apparently decreasing. However, radio apparatus may produce damage, and a discussion of the matter may result in future prevention of damage.

In this paper the subject will be considered under four general headings.

1. Wherein dangerous shocks may be received from radio apparatus.
2. Wherein radio apparatus provides a path for currents other than radio currents.
    (a) Lightning.
    (b) Antennas coming into contact with lighting or power lines.
3. Wherein radio apparatus provides the current or potential by direct discharge.
4. Wherein radio apparatus provides the current or potential by induction.

1. Injurious shocks may be received from the transmitter circuits used in very high power stations or in lower power stations should the operator come in contact with the power transformer secondary when the transformer is disconnected from the radio circuits. Radio frequency currents are usually, at worst, only disagreeable.

There are, or were, a few cases of dangerous practice along these lines. One was to shunt the operating key, so that the transformer secondary was at a fairly high potential when the key was open. Another dangerous method and probably by

*Delivered before The Institute of Radio Engineers, New York, June 2, 1915.

Digitized by Google

far the most dangerous to the life of the operator, was to use alternating current primary generators which gave an open circuit voltage as high as 500 or 600 volts and connecting that high voltage circuit thru the operating key.

Possibly it is reasonably safe to use a generator open circuit voltage as high as 250 but, all things considered, it may be best to bring this voltage down nearer 110, even if efficiency of transformation has to be sacrificed slightly.

2 (a). The danger of fire being produced by lightning striking the antenna is apparently less than the danger in ways mentioned under headings 2 (b), 3, and 4. Personally, I have never seen lightning strike an antenna, nor have I seen evidence that lightning has struck an antenna. However, I have frequently seen antennas discharge to ground when lightning apparently struck at some distant point. For example, in one case, using an antenna 200 feet (60 meters) high, the discharge jumped a gap of 3.5 inches (8.7 cm.) to the ground. On several occasions, in mountainous districts, I have seen lightning striking apparently on all sides of a radio station. On one such occasion, lightning struck a one-story house about six blocks from an antenna 200 feet (60 meters) high. On another such occasion, lightning apparently struck a high tension line near the radio station, judging from the crash which was apparently coincident with the flash and from the fact that the high tension transformer in the sub-station within a couple of hundred feet was burned out.

2 (b). At one time a report was brought in that lightning had struck a radio station burning up the receiving apparatus. On investigation it was found that someone had changed the antenna wires from their former position and had placed them across and above a 1,200 volt line. When the ropes supporting the antenna stretched, the antenna dropped down on the 1,200 volt line and grounded this line thru the receiving apparatus, burning up the receiving apparatus. On other occasions, antenna wires have dropped across telephone lines, and lighting and power circuits. In the case of the telephone lines, the radio transmitters discharged to the telephone line, usually short-circuiting the telephone lightning arresters; while in the case of the lighting and power circuits, the power circuits usually were short circuited, burning out fuses. However, in those cases, had the receiving instrument been connected, it is possible that the power circuits might have discharged thru the receiving instruments and burned them.

Digitized by Google

In cities, where lighting, power and telephone circuits are exposed, trouble may arise from antennas dropping across such wires, and in the larger cities where fire alarm circuits and telephone circuits frequently run across the roofs of houses, these circuits may be frequently damaged by antenna wires dropping across them and by their receiving direct discharges from the transmitters.

The greatest number of fires I have noticed starting from direct discharge of transmitters have been where roof insulators or deck insulators leaked current to the roof or deck, and where the roof or deck was of some combustible material. However, none of these fires have resulted in serious conflagrations, probably because they almost invariably occurred during rain or very damp weather, the dampness or rain serving both to short-circuit the insulator and put out the fire.

Portions of transmitters, such as condenser supports, transformer supports, etc., have frequently been charred to some extent. There is less danger of fire being caused by the apparatus which is mainly in use now because, with the exception of auxiliary apparatus as used by one company but now being discontinued, the plain antenna method of connection of the transmitter has been discontinued. This plain antenna connection brings the full spark gap potential to the roof or deck insulator, thereby causing it to break down. A majority of the cases observed where the roof or deck was set on fire were brought about by this type of apparatus.

For the benefit of persons who have not given thought to the subject of insulating radio transmitters, a few points concerning insulation may be proper. These points refer mainly to the transmitter and include the antenna.

A. Air is a good insulator. Its insulating qualities are least liable to be affected by dust, moisture, or age; also, it is cheap. That is, it is desirable to use plenty of air space, when practicable, between points where a discharge might take place.

B. Long and narrow surface insulation is desirable, much on the same principle that a long, narrow conductor has a higher resistance than a short, thick one.

C. Insulators having corrugated surfaces, or surfaces which furnish tortuous paths, are desirable, as such insulators require radio frequency currents to travel over long paths. For the same reasons, such insulators are desirable for direct current and audio frequency potentials.

D. Non-combustible, non-absorbent materials (for example,

Digitized by Google

porcelain) are preferable for insulators where it is possible to use them.

E. Insulator surfaces should be kept clean and dry.

In the earlier days of radio work, a common method of bringing the antenna thru the wall of the house was to bring this connection thru the middle of a large window pane. This practice was usually fairly satisfactory and not very expensive.

For inside work, the writer adopted a general rule of providing surface insulation equal to eight times the sparking distance thru air. For example, if the wire used in the circuit would spark to objects at a distance of one inch (2.5 cm.) thru air, this wire was held away by a porcelain rod one inch (2.5 cm.) in diameter and eight inches (20. cm.) long.

Porcelain cleats in series are probably as inexpensive an insulator as may be used for guying small antennas, considering their insulating qualities.

4. For the purpose of this paper, the currents which are set up in conductors not connected to antenna, but due to the radio frequency currents in that antenna, will be referred to as "induced radio currents", and the transference of energy from the antenna to other unconnected circuits will be referred to as "by radio induction".

The greatest damages from fire which is known to me have occurred where the transmitters were not connected with the point which took fire. In these cases the transmitter caused high potentials in conductors which were more or less distant from the transmitter; that is, these conductors acted somewhat as receiving antennas, and were close enough to rise to a high potential. Where these conductors consisted of telephone circuits the lightning arresters provided on the telephone circuits usually short circuited to ground by the fusing of the metal in the arrester.

This grounding of the telephone circuits usually rendered the telephone circuit inoperative. In the cases of lighting and power circuits carrying direct current or alternating current, such as 60 cycle alternating current, the high potential radio frequency alternating current induced on these lines was apparently superimposed on the direct current or audio frequency alternating current. The radio frequency current produced on these lines was frequently of very high voltage comparatively while the other current (direct, or audio frequency) on the lines was of comparatively high amperage. When the radio potential occurred at a point within striking distance of an object at op-

Digitized by Google

posite potential, it apparently discharged and carried the direct current or audio frequency current over after it. In many cases the arcs so formed held until the terminals of the arc or part of the circuit burned away. Power transformers, lighting transformers, motors, generators, relays, magnetos, watt meters, ammeters, volt meters, lamp sockets, rosettes, etc., burned out or were rendered inoperative apparently from this cause. On a number of occasions lamp cord carrying 110 volt direct current, or 60 cycle alternating current, has been short circuited, and on one occasion an 8 foot (2.4 meters) drop cord disappeared in flame and a nearby motor was short circuited. On other occasions, lamp cord lying against wooden moulding short circuited and burned, setting fire to the wooden moulding. On these occasions, people were nearby and put the fire out before it reached any material magnitude.

On one occasion receiving and transmitting apparatus were located very near to the transmitter. The result was that motor and generator windings, relay windings, reactance coil windings, etc., were repeatedly short circuited. This was stopped by providing radio frequency paths thru condensers across points which developed high radio frequency potential; also, by placing the wiring in grounded iron conduit, and the short sections of wiring of the switchboard in grounded lead covered wires; and finally, by placing a grounded wire netting screen between the transmitter and the apparatus. All of these expedients were put into effect before noticeable potentials were avoided.

Radio frequency currents possibly in some cases have been superimposed on high tension circuits of the transformers, at least across portions of the secondary of such transformers. It is not quite so easy to conceive how this radio frequency potential may occur in the secondary where so many turns of fine wire are used.* However, when transformers were placed in certain relation and near radio frequency circuits they broke down sometimes between sections and sometimes from secondary to primary, and similar transformers when substituted and moved further away or turned at an angle did not break down.

In the United States in 1901, in order to prevent induction in mast guys, these guys were made of rope. In 1902, owing to the stretching and contraction of the rope in dry and wet weather, the writer substituted steel guys with rope blocks and falls at

*A probable explanation is the distributed capacity of the secondary windings and consequent internal resonance effects with breakdown.

Digitized by Google

the bottom of the guys to serve both as insulators and as means for adjusting the guys. About this time, or before, others used wooden strain insulators in the guys. On some occasions both the rope insulators and the wooden strain insulators were burned by current leakage between the guys and ground. Even on shipboard, attempts were made at times to insulate guys and stays between masts. However, owing to the difficulty of providing insulation which would not leak, the principle of thoroly grounding the stays and guys was adopted. Stays and guys and other metallic conductors, such as hand rails, occasionally discharged to passengers, causing considerable excitement and fear on the part of some steamship companies that passengers might be electrocuted. The remedy used for this was thoroly to ground stays and guys, etc. Even the metal whistle cords on vessels occasionally discharged to damp wood work, etc., and often a person who tried to manipulate the whistle received a shock. These were grounded by using flexible wire ground connection. Steel beams, steam pipes, long bolts, anchor chains, and other conducting materials, on vessels, have been known to spark to ground or to other conductors. Conduits containing electrical wiring have apparently discharged to the ends of wiring where the conduits were not grounded. Metal roofs in the vicinity of land stations, and metal roofs of wharves, have discharged to ground, causing charring of the wood to such an extent that fear of fire resulted.

On account of sparking on their vessels, one line had a tendency to accuse the radio apparatus of being responsible for nearly anything that went wrong with the electrical circuits on the vessel, even going so far as to say that the radio currents went down thru the vessel and into the water condenser of the engine and caused electrolysis to such an extent that the water condenser had to be replaced!

On a line where the vessels were almost entirely constructed of wood, sparking, charring, and injured apparatus resulted at a number of points. The mast stays were wrapped with houslin and passed thru thimbles connected to the hull of the vessel, thereby insulating the mast stay from the hull of the vessel by the houslin. This houslin was set on fire and burned away, due to the sparking between the mast stays and the hull of the vessel via the thimble. On these vessels the mast head lights, running lights, and port and starboard lights, were connected to the pilot house signal light switch board by means of rubber covered twin conductors without metal covering. All of these signal light

Digitized by Google

circuits were burned out from time to time due to sparking across the lines or between the lines and ground. Annunciator circuits and call bell circuits thruout the vessels discharged to metal portions of the ship, and in some cases caused slight charring of woodwork.

On one occasion a steamship company asked that their vessel be gone over with a view to preventing any possibility of igniting explosives which they expected to carry. In this case it was recommended that all metallic conductors in the hold and in the vicinity of the hold be thoroly grounded and electrically connected together, even the short metal ladders and supports which extended from one deck to another.

Three instances are recalled of wooden masts set on fire due to the discharging of guys to each other thru the woodwork of the mast. In two of the cases the masts were burned off several feet from the top. In these cases the guys were 50 feet (15 meters) or more from the antennas.

It has been found that radio currents were induced in the metallic paint on masts and on some occasions the metal paint was removed and a portion of the mast varnished. Some years ago it was the rule to make all radio masts of wood. Also wooden top masts have been required on shipboard because of the radio apparatus.

Regarding the ability of sparks to start fire, that obviously depends on the heat developed by the spark and the heat required by the combustible material. Very small sparks are almost universally used for igniting gas or gasolene vapor in gas engines, and it is quite possible that similar gas might be ignited by equally small or smaller sparks on shipboard or at other points near radio stations. Sparks developed by radio transmitters might be capable of igniting oils such as are found, for example, in the paint lockers on vessels. Theoretically, radio might cause distress conditions by setting the ship on fire and then relieve these conditions by bringing aid!

While the paper has been confined practically entirely to personal observations, the conclusion is not to be drawn that the damaging results always occur. The instances mentioned practically cover all the cases noted during a period of about 15 years use of radio frequency circuits, including radio frequency apparatus operated under a large variety of relations to adjacent conductors at stations on both coasts of the United States, at numerous points inland, and on the vessels of several nations.

Digitized by Google

Protection against radio frequency currents of dangerous potential being induced in low potential direct current of audio frequency circuits may be brought about to a considerable extent by taking advantage of the ways in which radio frequency currents differ from direct current and audio frequency currents.

Condensers of small capacity impede radio frequency currents very much less than audio frequency currents; (that is, radio frequency currents usually find an easy path thru small condensers, while practically no 60 cycle current or direct current will flow thru small condensers.) For practical purposes small condensers may be assumed to be good conductors for radio frequency currents and insulators for direct current and alternating current having frequencies in the neighborhood of 30 to 500 cycles.

Condensers have been installed in series with fuses to ground. This practice is objectionable because if the fuses burn out, the lines are left unprotected at a time when such protection is most likely to be needed, and unless the fuses are in some way arranged to notify some person, it is quite probable that they will not be known to have burned out until after damage occurs to the low tension circuits.

Mica condensers in which lead foil was used have been found to provide automatic self fusing devices without destroying the service ability of the condenser; for example, when a sheet of mica punctured making a small hole, the lead foil melted away from around the hole until the arc was extinguished and the condenser then operated as before.

Radio frequency currents do not penetrate very far into the conductor, or flow to any great extent in a conductor when that conductor is screened by a concentric conductor such that the radio frequency may flow in the concentric conductor; thus, for example, very little if any radio frequency current will be induced in a pair of rubber covered copper wires enclosed in an iron conduit, where the iron conduit is grounded at intervals.

Low potential circuits have often been protected from radio frequency potentials by grounding the low potential circuits thru high resistance rods made up of carbon and clay; and in some cases by using incandescent lamps between the conductors and ground. The writer has always considered this an objectionable practice, because to some extent it grounds the low potential circuits, which are usually better ungrounded. Also, according to the experience of the writer, these high resistance grounds have apparently offered, as a rule, greater impedance

Digitized by Google

to the radio frequency currents than small condensers offered. Slate switchboards sometimes served as protectors to low frequency circuits because their resistance was sufficiently low to allow them to act much as the high resistance protective rods.

Less trouble has occurred since more metal has been used in the construction of ships, in the form of bulkheads, decks, and supports. In addition, the doing away with wiring in wooden moulding and the substitution of metal moulding, conduit, and metal covered cable has prevented radio frequency currents from being produced in the direct current and audio frequency wiring. Lead covered wire has been used sometimes, but has occasionally caused trouble when the lead has been mechanically forced thru the insulation and against the copper. It is probably preferable to use lead covered wire in protecting metal conduit with drains in the lower portions of the conduit to take care of sweating, etc.

Besides preventing sparking, another reason for thoroly grounding the stays and mast guys on vessels was the assumption that less energy is absorbed from the radio waves by thoroly grounding these stays than that which would probably be consumed in the resistance over leaking insulators.

The increasing knowledge and improving practice of professional radio engineers decreases the probability of damage. However, inexperienced persons instal transmitting and receiving stations from time to time, using such various types of apparatus as their circumstances and knowledge provide. Such stations as these are frequently erected in private houses, where sparks may occur on combustible material, and where telephone and lighting wires may not be protected by conduit or grounded metal covered wire, and where the antennas may be above or may parallel nearby telephone, fire alarm, lighting, and power wires. It might be useful to offer a set of rules to cover the various possibilities, but that would require very careful study, if these rules were drafted, to prevent imposing hardship on the young experimenter and radio student, who generally is limited as to means.

Rules might be prepared by a Joint Committee of the American Institute of Electrical Engineers and The Institute of Radio Engineers. These would make a useful addition to the Underwriters' Rules and improve engineering practice.

The radio laws which require low decrement and practically single waves to be radiated from transmitters, made for the purpose of preventing interference, may serve as a protection against radio transmitters causing damage. These laws, with

Digitized by Google

their resulting regulations, aid in eliminating the plain aerial type of transmitter whereby the antenna was raised to excessively high potentials, and because of the lower decrement, nearby circuits, unless their natural period is somewhat near that of the radio frequency, may not be excited to such an extent. High group frequency transmitters and especially transmitters of constant amplitude waves use lower voltage for equal power, which results in lower voltages being induced in nearby conductors. These types of transmitters are coming into general use and the constant amplitude wave transmitters may be the transmitters of the future. Therefore, the probability of damage should continue to decrease.

When the current flows in an antenna, magnetic and electrostatic fields are produced around that antenna; therefore all conducting materials in these fields are conductors in the dielectric of a condenser, and at the same time they are conductors which cut a magnetic field. Considering the antenna as one plate and the earth as the other plate, and the air between all parts of the antenna and the earth as the dielectric, all conductors within this air space will be at a different potential from both the antenna and the earth, while this condenser is being charged. As the antenna may be periodically charged to a high potential, the conductors in the dielectric may be periodically at a high potential with respect to earth, depending on their distance from the earth and from the antenna. If these conductors are at any time raised to a potential sufficiently high to break down the solid or air insulation between them and earth, they will discharge or spark to earth. Now, if these conductors are carrying another current such as direct current with a direct current potential difference to ground, then the direct current will as a rule, it may possibly be said, follow the spark, and establish an arc which may hold until the circuit is opened by some portion burning away whether that portion be a fuse, a wire line, or generator winding. In the same manner both terminal wires of a motor or generator may spark simultaneously to the armature core, and produce a short circuit. This may occur whether or not the motor or generator is grounded because the motor or generator usually occupies a relatively different position in the dielectric from that occupied by the line wires.

Where conductors are within sparking distance of the antenna a discharge may take place, altho the conductors may be insulated from ground and from the antenna, and this for the same reason that such conductors discharge to ground. For example,

Digitized by Google

antenna circuits frequently discharge to such small masses of metal as wood screws, altho the surrounding wood is a good insulator.

Conductors are usually so placed as to cut the magnetic lines emanating from the antenna or the closed circuit of the transmitter; and a potential difference between the ends or portions of a system of such conductors may result which will break down the insulation. If these ends or portions are, for example, the opposite terminals of a motor or generator, or the terminals of a magnet, a short circuit may result. The electrostatic and magnetic fields may work together to produce such damage.

The shorter waves formerly used may have corresponded more nearly to the natural wave lengths of conductors which were found on shipboard in the lower potential circuits than do the longer waves used at present. When the conductor which tends to spark to ground or to the frame of a dynamo is connected to ground or to the frame thru a condenser, and where that condenser is relatively of much higher capacity than the capacity of a conductor to ground or to the object to which it tends to spark, the effect is probably somewhat similar to bringing the conductor quite near to the ground or the frame, and the nearer the conductor is to ground or to the frame, the lower the potential difference that exists between the conductor and ground or frame. That is, the conductor will be brought to a point of lower potential in the potential gradient between the antenna and ground. Or this protective condenser may be possibly regarded with fair correctness as a very low impedance so far as the radio frequency potential is concerned; and where a relatively low impedance is in circuit, the potential across that impedance must be relatively low. In other words, a relatively low impedance is provided for the radio frequency current around the insulation provided for the direct or audio frequency current.

Test made at the United Wireless Telegraph Company's Manhattan Beach station on Aug. 21, 1909, are interesting in these connections.

Referring to the Figure:

1, 2, 3, 4, 5, 6, 7, 8, 18, 19 represent the United Wireless transmitter.

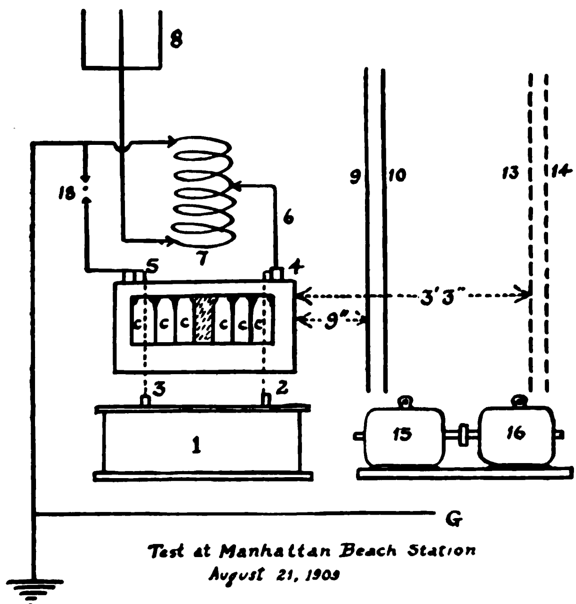
1. 2 K. W. 60 cycles transformer.

2, 3, 4, 5. Connections between transformer secondary and condenser.

Digitized by Google

6. Connection to coupler.
7. Helical coupler (oscillation transformer).
8. Antenna.
18. Spark gap.
19. Ground.
c—c Condenser (Leyden jars).

9, 10, 13, 14 represent the relative position of two test wires each of number 10 B. & S. rubber covered copper wire* 5 feet (1.5 m.) in length. The wires were parallel and 3 inches (7.62 cm.) apart. These wires were open and insulated, and their lower ends were either brought near together or near to the earth or motor generator, so as to ascertain over what length of gap they would discharge.



Test at Manhattan Beach Station
August 21, 1909

15–16 represents a 2 K. W. Holtzer Cabot motor generator, on an iron base, insulated from ground. Motor (15), Generator (16). The motor generator was disconnected, power for the transmitter being taken from the city mains.

G. Wire connected to copper plate in earth, approximately 15 feet (5 m.) long.

of number 10 wire =0.102 inch =0.259 cm.

Digitized by Google

The transmitter operated at full power, and radiated two waves (at 500 and 960 meters).

a. Test conductors at 9 and 10. No noticeable discharge between two lower ends.

b. Same at 13 and 14.

c. 9 or 10 discharges over 0.25 inch (0.6 cm.) air gap to ground (*G*).

d. 13 or 14 discharges over 0.17 inch (0.4 cm.) air gap to *G*.

e. 9 or 10 discharges over 0.06 inch (0.15 cm.) gap to motor generator (insulated from ground).

f. 13 or 14 discharges over 0.03 inch (0.08 cm.) gap to motor generator (insulated from ground).

g. 9 in grounded Greenfield conduit discharges approximately 0.01 inch (0.025 cm.) to ground (*G*).

h. 9 in ungrounded Greenfield discharges 0.22 inch (0.55 cm.) to *G*.

i. 9 in grounded Greenfield discharges 0.14 inch (0.35 cm.) to ungrounded motor generator.

j. 9 in Greenfield connected to motor generator, discharges less than 0.01 inch (0.025 cm.), to motor generator.

k. 9 in Greenfield connected to motor generator shows no discharge to motor windings.

l. 9 in grounded Greenfield discharges 0.14 inch (0.35 cm.) to motor windings.

m. 9 connected thru 0.013 μf. condenser to motor generator shows no discharge to either motor generator frame or motor windings.

n. Motor generator discharges 0.22 inch (0.55 cm.) to ground (*G*) when 9 is connected to motor generator thru 0.013 μf.

o. Motor generator shows no discharge to ground when connected to ground thru 0.015 μf. (conductor 9 was connected to motor generator thru 0.013 μf.).

Considering the antenna and earth together with the intervening air as a condenser, if we wish to protect conductors in this air dielectric against discharges from one plate or the other of this condenser, we must do one of two things: Either thoroly insulate the conductors to be protected or connect them electrically to the plate to which they have a tendency to discharge. That is, they must be thoroly insulated or made part of one plate or the other. As the insulation between low voltage circuits and ground is as a rule only sufficient to insulate the normal potential on the low voltage circuits, it is necessary to provide means for connecting these circuits to ground so far as radio

Digitized by Google

frequency currents are concerned, or to enclose them within the ground plate of the condenser rather than in dielectric.

The case is one of conductors subjected to alternating stress in the dielectric of a condenser and at the same time to an alternating magnetic field.

The problem is to prevent these conductors from sparking. The usual solution is to ground thoroly all conductors which are not there for the purpose of carrying current, and to enclose current carrying conductors in grounded metal coverings (e. g. metal conduit). Where this is not practicable, it is desirable to connect the current-carrying conductors to ground and to each other thru condensers (e. g. lead foil and mica condensers of approximately 0.17 μf. capacity tested at 500 volts, 60 cycle alternating current and enclosed in copper water-tight cases). In building a radio station, it is desirable to place all current-carrying conductors (other than radio) underground so far as practicable (and especially telephone conductors). The first continuous grounded metal deck of a vessel, below the radio transmitter, may be usually considered as the surface of the ground in so far as this protective effect is concerned.

SUMMARY: Various types of possible danger from radio installations are considered: shocks to the operator, short-circuit from lightning or from contact with high tension power lines, breakdown from the high tension circuits of the radio transmitter itself, and harmful inductive effects from radio transmitters.

In each case, instances are given together with the proper means of avoiding the undesired effect. In this connection, some detailed experiments are described.

Digitized by Google

DISCUSSION

Benjamin Liebowitz: In the protection of radio frequency apparatus, one of the most important points is the insertion of choke coils to localize properly the radio-frequency energy. I do not think it is as fully appreciated as it should be that multiple-layer coils are almost useless for this purpose. Because of their large effective distributed capacity, radio frequency currents are propagated with great ease thru such coils, and often with disastrous results. Thus, in one instance, I employed as a choke coil an inductance of about 600 turns of number 18 B. and S. wire* wound in 30 turns per layer, and burnt out a generator in consequence. I replaced this coil by six single-layer spirals about twenty-four inches (61 cm.) in inside diameter, each spiral having eighty turns of copper ribbon 0.50 by 0.01 inch (1.27 by 0.025 cm.) in section insulated by paper ribbon of the same section. The six spirals in series had somewhat less inductance than the multiple-layer coil first used, but to currents less than 100,000 cycles in frequency they were an almost perfect barrier. It cannot be too strongly emphasized that distributed capacity is just as undesirable in choke-coils as it is in radio frequency circuits.

* Diameter of number 18 wire = 0.040 inch = 0.010 cm.

Digitized by Google

Digitized by Google

SUSTAINED WAVE TRANSMISSION CHART*

By

TYNG M. LIBBY

(BREMERTON NAVY YARD)

Radio engineers are frequently called upon to estimate the range of radio transmitters, and to predetermine the height of antennas, wave length, and power required to cover a given range under average conditions. While estimates may be made from a wide experience with a large number of stations, the writer is of the opinion that closer approximations may be made by the calculation of these factors by means of semi-empirical formulae derived thru the correlation of data obtained thru tests. In order to determine which formula most nearly represents the observed results of daylight transmission, a comparison of the following sustained wave formulas has been made:

The Sommerfeld[1] theoretical formula:

$$I_r = 377 \frac{h_1 h_2 I_s}{\lambda d R} \sqrt{\frac{\theta}{\sin \theta}} \cdot \varepsilon^{-\frac{0.0019 d}{\sqrt[3]{\lambda}}} \qquad (1)$$

The Austin[2] semi-empirical formula:

$$I_r = 377 \frac{h_1 h_2 I_s}{\lambda d R} \sqrt{\frac{\theta}{\sin \theta}} \cdot \varepsilon^{-\frac{0.0015 d}{\sqrt{\lambda}}} \qquad (2)$$

The Fuller[3] semi-empirical formula:

$$I_r = 377 \frac{h_1 h_2 I_s}{\lambda d R} \sqrt{\frac{\theta}{\sin \theta}} \cdot \varepsilon^{-\frac{0.0045 d}{\lambda^{\sqrt{2}}}} \qquad (3)$$

The formula[4] given in Eccles' "Hand Book":

$$I_r = 4.25 \frac{h_1 h_2 I_s}{\lambda d} \cdot \varepsilon^{-\frac{0.0045 d}{\lambda^{\frac{3}{2}}}} \qquad (4)$$

In these formulae, I_s and I_r are sending and receiving

---

* Presented before THE INSTITUTE OF RADIO ENGINEERS, Seattle Section, June 10, 1916.

[1] A. Sommerfeld, "Ann. der Phys.," 28, 1909.

[2] "Bulletin of the Bureau of Standards," volume 11, number 1, Nov., 1914.

[3] L. F. Fuller, "Proc. A. I. E. E.," volume 34, number 4.

[4] "Hand Book of Wireless Telegraphy and Telephony," Eccles.

Digitized by Google

antenna current respectively in amperes; h_1 and h_2 the effective heights in kilometers of the transmitting and receiving antennas, respectively; λ is the wave length and d the distance, both in kilometers; R is the radio frequency resistance in ohms, of the receiving system. The term $\sqrt{\frac{\theta}{\sin \theta}}$ accounts for the effect of the curvature of the earth, θ representing the angle, at the center of the earth, subtending the distance d. For practical purposes this term may be considered equal to unity.

Table 1 gives some of the results of receiving tests at Darien,[5] with audibilities calculated from formulas (1), (2), (3), and (4). The received watts corresponding to unit audibility[5] were taken as 1.23×10^{-15} and the audibility taken as proportional to the received current.

The values given by equation (1) are in fair agreement with the observed results at the shorter distances. For the longer distances, the calculated values are so low as to support the conclusion of Dr. Austin[5], that equation (1) represents the very lowest values of received energy, and that at the greater distances, these are strengthened by reflection from the upper strata.

Equation (3) gives absurdly high values as compared with the observed results, and might possibly be due to difference in types, and methods of manipulation of receiving apparatus, etc., when this formula was derived.

Equation (4) is in closer agreement with the observed values on shorter distances than the Austin formula. At the greater distances, however, the values are extremely high. This formula as given by Eccles, assumes a value of 25 ohms for R. In these computations, the term R was introduced into the equation, which changed the coeffici ent 4.25 to 106.25.

Attention should be called to the publication in different places of equations (3) and (4) as Fuller's equation. These two equations are not at all in agreement, and without a copy of Mr. Fuller's original paper,[3] one would be at a loss as to which was the "Fuller Formula."

Of the four equations, (2) gives the most consistent values, and as a whole may be taken as a close approximation. It is noticed that the audibility of Arlington as calculated by equation (2) is in good agreement with the observed value. It is suggested that this may be due to the fact that equation (2) was derived from data taken at that station.

[5] L. W. Austin, "Experiments at the U. S. Naval Radio Station, Darien, Canal Zone," "Proc. I. R. E.," volume 4, number 3, 1916.

Digitized by Google

TABLE I

Transmitting Station	I_s Amps.	λ Meters	h_1 Meters	R Ohms	Dist. Km.	Audibility				
						Obs.	Equa. 1	Equa. 2	Equa. 3	Equa. 4
Arlington................	60	6000	61*	23.2	3330	5000	1840	7780	18180	6080
Tuckerton	115	7400	120	25	3430	10000	6040	25780	68680	22360
Sayville..................	140	9400	80	14	3520	7500	6120	25900	74650	18780
San Diego................	35	3800	55	26.5	4670	0–100	113	911	1400	547
San Francisco............	40	6500	96	23.5	4820	0–1000	295	2334	8540	2020
Honolulu.................	60	10000	96	13.5	8500	150	16	514	6640	2440
Nauen	150	9400	120	29	9400	200	16	750	1260	4860
Eilvese...................	140	7400	120	25	9160	200	10	500	7030	2840

* h_1 corrected from short range observations and found to be approximately one-half of height to geometric center. h_1 for other stations taken as 80 per cent. of height to geometric center.

Effective height of Darien antenna, 146 meters.

Digitized by Google

The writer has made many audibility tests on naval ships and shore stations, and while the data obtained cannot be disclosed, it may be stated that the values calculated by equation (2) were found to be in fair agreement with the observed values.

A simple algebraic solution of equation (2) for the values λ and d is impossible, since they occur linearly and exponentially. For the purpose of comparing observed results with equation (2) predetermining λ, h_1, h_2 and I_s to cover a given range, and for readily solving for d, a chart has been prepared by the writer. This chart is similar to the one for spark transmitters, which was submitted for publication by the writer's co-worker, Mr. H. G. Cordes.[6]

The radio frequency resistance of the average receiving system is about 25 ohms. Assuming this value for R and stating equation (2) in English units:—

$$I_r = 757 \frac{h_1 h_2 I_s}{\lambda d} \cdot \varepsilon^{-\frac{0.0877 d}{\sqrt{\lambda}}} \tag{5}$$

I_r in micro amperes.
I_s in amperes.
h_1 and h_2 in feet.
λ in meters.
d in nautical miles.

Dividing (5) algebraically, and stating logarithmically:

$$log_{10} \frac{I_r}{757} + log_{10} \frac{\lambda}{h_1 h_2 I_s} = \frac{0.0877 d}{\sqrt{\lambda}} log_{10} \varepsilon - log_{10} d \tag{6}$$

A number of curves (the broken curves in the chart) for various values of I_r are plotted with ordinates $\frac{\lambda}{h_1 h_2 I_s}$, and abscissas,

$$log \frac{I_r}{757} + log \frac{\lambda}{h_1 h_2 I_s}$$

For each of a number of wave lengths additional curves (full line curves in the chart) are plotted over the same abscissa equated thru the expression

$$-\frac{0.0877 d}{\sqrt{\lambda}} log \varepsilon - log d$$

with d as ordinates.

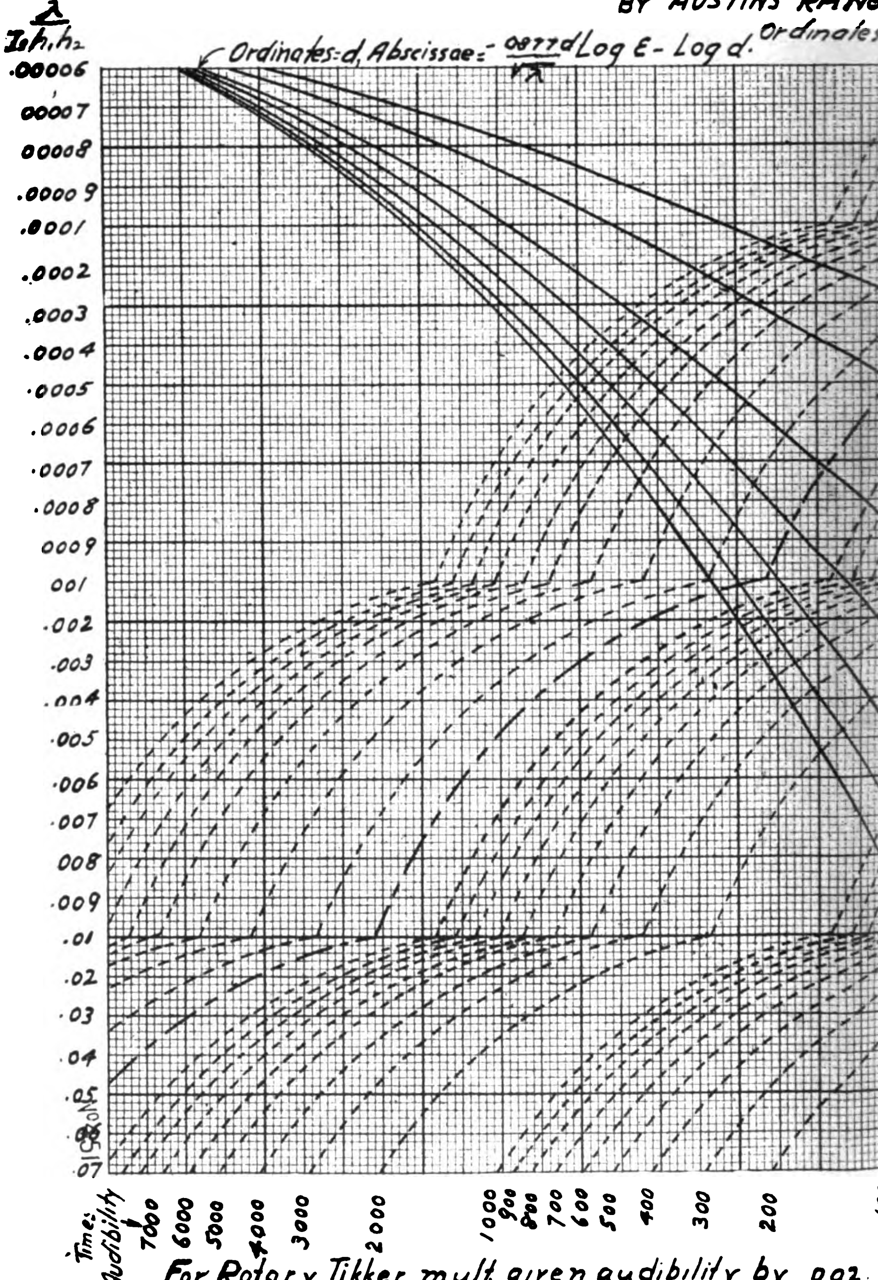
The I_s curves (broken line) are marked in terms of audibility using the oscillating audion as a detector, the received energy required for unit audibility being taken as 1.23×10^{-15} watts[5],

[6] "Electrical World," volume 66, number 23, 1915.

Digitized by Google

Digitized by Google

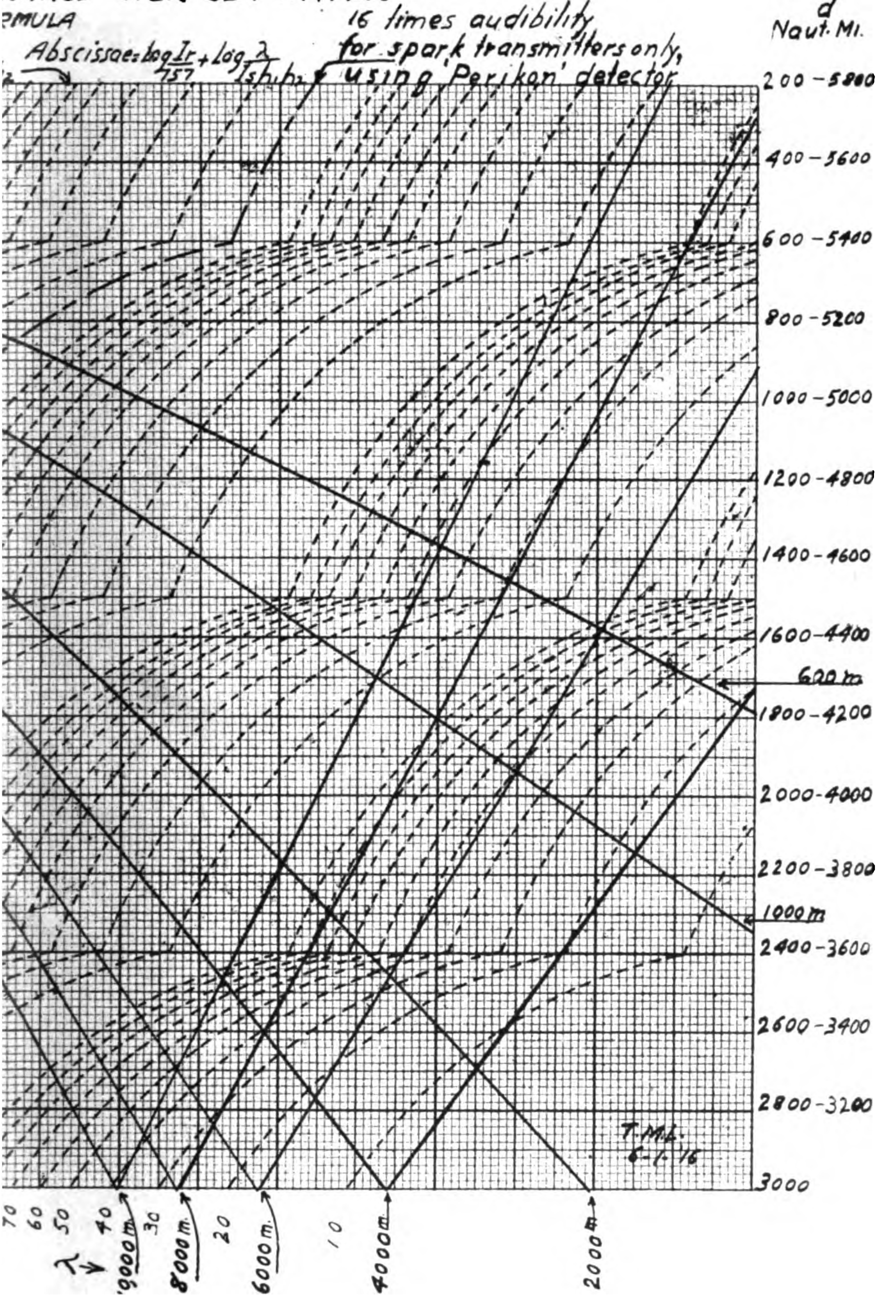
APPROXIMATE DAYLIGHT TRANSMISSI
BY AUSTIN'S RANG



For Rotary Tikker mult. given audibility by .002.

Digitized by Google

RANGE OVER SEA WATER



Digitized by Google

and the audibility assumed to be proportional to I_r. The current required for unit audibility thru 25 ohms, using the ultraudion detector, is therefore 0.007×10^{-6} amperes.

Fuller found that the received energy required for unit audibility using a rotary tikker is 3.2×10^{-10} watts[3], or 3.56×10^{-6} amperes thru 25 ohms. Since the audibility with the tikker detector varies directly as the current, the audibility curves in the chart may be used for that detector by multiplying the given audibility by $\frac{0.007 \times 10^{-6}}{3.58 \times 10^{-6}}$ or 0.002.

If using a detector other than the ultraudĭon, the value of the curves in terms of I_r can readily be determined from their values expressed in audibility.

To solve for d with a given set of transmitter values, proceed as follows:

1. Compute $\frac{\lambda}{h_1 h_2 I_s}$.

2. Locate this value on the left-hand ordinate scale and follow in horizontally to the intersection of the broken curve for the audibility desired.

3. From this intersection, proceed vertically to the solid line for the wave length used.

4. From this last intersection, proceed horizontally to the right, and read the required value of d on the right-hand ordinate scale.

To predetermine the value of $\frac{\lambda}{h_1 h_2 I_s}$ required to cover a given range, the operations are just the reverse of these for determining d.

To find the value of I_r as calculated by equation (2) when all other factors are known:

1. Locate d on the right-hand ordinate scale, and follow in horizontally to the solid curve for the wave length used. (Note the abscissa at this intersection.)

2. Compute $\frac{\lambda}{h_1 h_2 I_s}$.

3. Locate this value on the left-hand ordinate scale, and follow in horizontally to the abscissa noted in operation 1. The audibility curve upon which this last intersection lies, is the audibility required. If this last intersection does not lie exactly on one of the audibility curves plotted, it is but a simple matter to interpolate. To express the audibility in micro-amperes thru 25 ohms, multiply by 0.007.

Digitized by Google

In predeterminations, under ordinary conditions, the writer uses a factor of safety of 12 times the minimum audibility required. In exceptional cases, such as high intervening mountains, in short distances, and in the use of short wave lengths, a factor of safety of 16 times the audibility required, would not be too large.

The Austin-Cohen[7] daylight transmission formula for damped transmitters

$$I_r = 4.25 \frac{h_1 h_2 I_s}{\lambda d} \cdot \varepsilon^{-\frac{0.0015\,d}{\sqrt{\lambda}}} \tag{7}$$

has been found to agree fairly well with observed results, on wave lengths up to 4000 meters and distances up to 2000 miles, where the transmitters were coupled loosely enough to radiate but one wave.

Expressed in English units (7) becomes

$$I_r = 212 \frac{h_1 h_2 I_s}{\lambda d} \cdot \varepsilon^{-\frac{0.0877\,d}{\sqrt{\lambda}}}$$

Transposing and stating logarithmically

$$log_{10} \frac{I_r}{212} + log_{10} \frac{\lambda}{h_1 h_2 I_s} = -\frac{0.0877\,d}{\sqrt{\lambda}} log_{10}\,\varepsilon - log_{10}\,d \tag{9}$$

It will be noticed that the right side of equation (9) is identical with that of equation (6). The full line curves for wave lengths in the chart, therefore, are the same for damped and sustained wave transmitters.

If in the chart, a set of I_r curves were plotted with ordinates $\frac{\lambda}{h_1 h_2 I_s}$ and abscissas $log \frac{I_r}{212} + log \frac{\lambda}{h_1 h_2 I_s}$, this chart could be used for both damped and sustained wave transmitters.

Dr. Austin has found that an audibility of sixteen, or 28×10^{-6} amperes thru 25 ohms, insures good communication thru strays and interference, using the electrolytic, or the perikon detectors.

In order to make the chart applicable to damped transmission, the dot and dash curve has been plotted, the value of I_r being taken as 28×10^{-6} amperes.

While it is admitted that a transmission theory, rather than a transmission formula is desired, I do not think that more sustained wave transmission data would be undesirable, and I make this attempt to stimulate activity in this line.

---

[7] "Bulletin, Bureau of Standards," volume 7, number 3, 1911; volume 11, number 1, 1914.

Digitized by Google

SUMMARY: The Sommerfeld, Austin, Fuller, and Eccles transmission formulas are compared with available data, and the conclusion reached that the Austin formula is most nearly correct. A chart is given whereby, given any five of the six quantities: wave length, transmitting and receiving antenna heights, distance of transmission, transmitting current, and received audibility, the sixth can readily be obtained. Tho specially intended for sustained wave reception using the ultraudion, it is shown that the chart can also be used for other detectors and damped wave reception.

Digitized by Google

Digitized by Google

QUANTITATIVE RELATIONS IN DETECTOR CIRCUITS*

(A Discussion on Mr. Armstrong's Paper on "A Study of Heterodyne Amplification by the Electron Relay.")

By

Benjamin Liebowitz, Ph. D.

The object of this discussion is to bring out certain fundamental relations in simple detector circuits, and thereby to determine directly the maximum amplification which can be attributed to the heterodyne principle. The chief assumptions are (1), that the predominant reaction in the detector circuit (D K of Figure 1) is that due to the resistance of the detector D, and (2), that this resistance is so high that the energy abstracted by the detector circuit from the oscillatory circuit LC is very small. Under these circumstances, there will be an

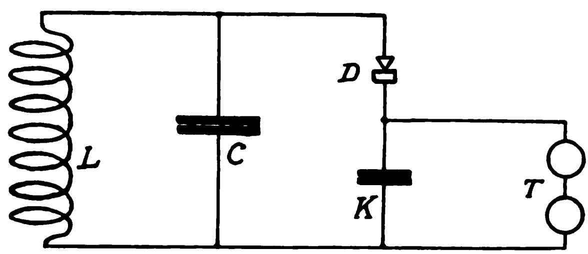


Figure 1—Typical Detector Circuit

approximately simple harmonic e.m.f. impressed on the detector if the received signals are simple harmonic, as we shall suppose, and the current thru the detector can then be determined.

Two types of detectors will be considered, viz., "perfect" rectifiers and "approximate" rectifiers. The method of procedure in each case is to compute the radio frequency currents as well as the audio frequency currents flowing in the detector circuit, and by comparison of these to determine what part of the

* Received by the Editor, November 1, 1916.

Digitized by Google

energy abstracted from the oscillatory circuit is useful in producing an audible frequency telephone current.

Case I. "Perfect" Rectifiers

A "perfect" rectifier may be defined as one which has a constant resistance in one direction and an infinite resistance in the other direction. The voltage-current characteristic for such a detector is shown in Figure 2.

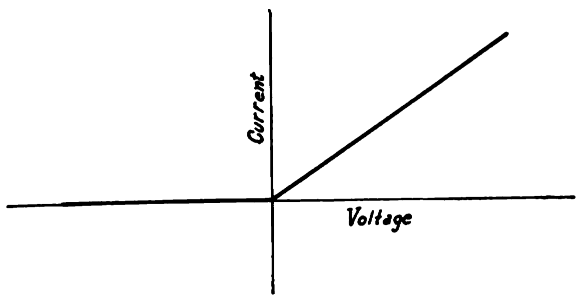


Figure 2—Characteristic of "Perfect" Rectifier

When a simple harmonic e.m.f. is impressed on a rectifier of this kind, the resulting current will obviously be a succession of sine loops, such as shown in Figure 3. If the e.m.f. is $e \sin pt$

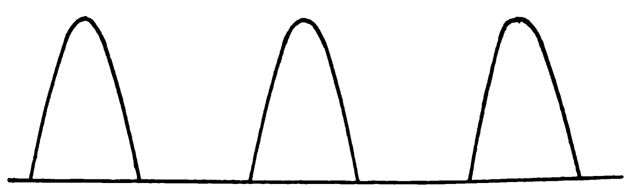


Figure 3—Current Thru "Perfect" Rectifier

and the finite resistance of the detector is R, the amplitude of these loops will be simply $\frac{e}{R}$.

This succession of loops is readily decomposable into a Fourier's Series. By the usual process the series is found to be

$$\frac{e}{R}\left\{\frac{1}{\pi}-\frac{1}{2}\cos pt+\frac{2}{3\pi}\cos 2pt-\frac{2}{15\pi}\cos 4pt+\cdots\right\}$$

Digitized by Google

We have here a rectified current of magnitude $\frac{1}{\pi}\frac{e}{R}$, a fundamental radio frequency current of amplitude $\frac{1}{2}\frac{e}{R}$, and a series of smaller overtones. If the rectified current is denoted by y_o and the amplitude of the fundamental radio frequency current by Y_p, it follows, therefore, that

$$y_o = \frac{2}{3} Y_p, \text{ approximately.}$$

Hence we see that *the magnitude of the useful current is only about two-thirds of the amplitude of the fundamental radio frequency current flowing in the detector circuit.*

The average rate at which energy is being drawn from the oscillatory circuit LC is $\frac{1}{4}\cdot\frac{e^2}{R}$ (being half of that which would obtain if the detector had resistance R in both directions). Of this energy, $\frac{1}{\pi^2}\cdot\frac{e^2}{R}$ is in rectified current, $\frac{1}{8}\cdot\frac{e^2}{R}$ is in fundamental radio frequency current, and the rest is in the overtones. That is to say, *of the total energy abstracted from the oscillatory circuit, about 40 per cent. is in the form of rectified current, 50 per cent. in the form of radio frequency current of fundamental period, and the remainder is in the overtones.*

In order to be heard, the continuous series of loops of Figure 3 may be broken up into trains of audible frequency, so as to convert the steady rectified current into one which rises and falls between zero and $\frac{1}{\pi}\cdot\frac{e}{R}$. This is equivalent to an audio frequency current of amplitude $\frac{1}{2\pi}\cdot\frac{e}{R}$, superimposed on a direct current, plus overtones. The energy relations are otherwise unchanged, for the preceding analysis is applicable to each train or to each loop of each train.

Instead of being broken up, however, the series of loops may be made audible by the heterodyne method. If the "other force" is of the same magnitude as the incoming e.m.f. (the "equal" heterodyne), then the loops will rise and fall between zero and $\frac{2e}{R}$. And since each loop is very nearly pure sine in shape, the above analysis is applicable as a close approximation, and we therefore obtain a beat frequency current of amplitude $\frac{1}{\pi}\cdot\frac{e}{R}$; which is twice that obtained without the heterodyne.

Digitized by Google

When, however, the local force, say of amplitude E, is large compared with that received, then the loops will rise and fall between $\frac{E+e}{R}$ and $\frac{E-e}{R}$. And if we applied the preceding analysis, we should still find that the amplitude of the beat frequency current is $\frac{1}{\pi} \cdot \frac{e}{R}$. So that *if the detector is a perfect rectifier, the heterodyne method gives twice as great a useful telephone current as the "breaking up" method, irrespective of the amplitude of the local current*; a result entirely in accord with that at which I arrived originally.[1]

In the sense that with a given "perfect" rectifier the heterodyne gives twice as great a telephone current as the "breaking up" method gives, and hence four times as much energy in the response, the heterodyne may be said to give a four-fold true amplification. This interpretation of "true amplification" was used by Mr. Armstrong in his paper, and is entirely justifiable; but it must not be taken to mean that the heterodyne puts four times as much energy into the telephone current as received frequency energy abstracted from the oscillatory circuit. This question will be taken up in greater detail in the next section.

The reason for the four-fold amplification becomes perfectly clear if we bear in mind that in the "breaking up" method of receiving sustained waves we subtract roughly half the available energy, whereas with the heterodyne method we add as much available energy as we had to begin with.

I have omitted many of the details of the preceding analysis and passed over several points, because, after the Fourier's series has been worked out for the succession of sine loops of Figure 3, the subsequent results become clear by physical reasoning, and also because the case of "approximate" rectifiers, which will now be taken up, is of much greater interest.

Case II. "Approximate" Rectifiers

The characteristic of an ordinary crystal rectifier differs from that of a "perfect" rectifier (shown in Figure 2) in that it runs slightly below instead of along the current axis for negative voltages, in that it has a finite instead of an infinite curvature at the origin, and in that it generally curves upward instead of being straight for positive voltages. The ordinary rectifier is therefore imperfect in two respects: it rectifies no alternating

[1] See these Proceedings, June, 1915, page 185, *et seq.*

Digitized by Google

current completely, and it rectifies relatively large currents better than small.

For purposes of analysis it is desirable to use a detector which rectifies small currents substantially as well as relatively large ones. To do this, the characteristic of the detector must have a rapid, tho finite, curvature at the origin, as shown in Figure 4. Such a detector will be assumed in our analysis, and will be called an "approximate rectifier."

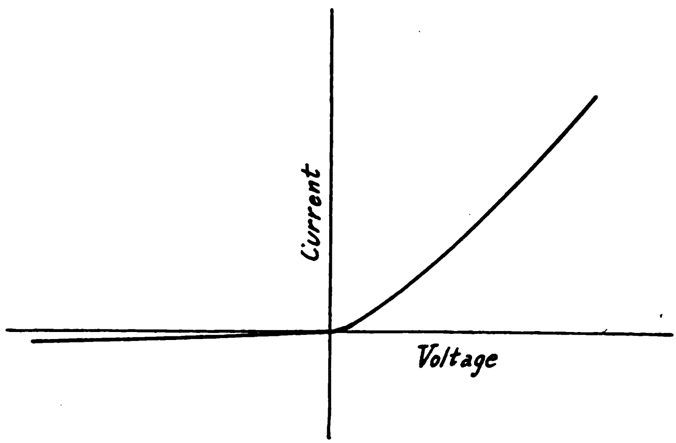


FIGURE 4—Characteristic of "Approximate" Rectifier

The curve of Figure 4 can be represented by a power series, or, with sufficient accuracy for all practical purposes, by a dozen or so terms of such a series. Furthermore, in order to satisfy our definition of an "aproximate rectifier," the sum of all the odd powers of the series must be nearly equal to the sum of all the even powers; for the odd powers change sign when the voltage becomes negative, whereas the even powers do not; so that if their sums are nearly equal, they will nearly cancel out for negative voltages and the series will be large only for positive voltages. Hence, if y is the current and v the voltage, the characteristic of our approximate rectifier is represented by

$$y = a_1 v + a_2 v^2 + a_3 v^3 + a_4 v^4 + \cdots, \tag{1}$$

subject to the condition, when v is positive that

$$a_1 v + a_3 v^3 + a_5 v^5 + \cdots = a_2 v^2 + a_4 v^4 + a_6 v^6 + \cdots + \Delta, \tag{2}$$

where Δ is a small quantity depending on v.

Digitized by Google

In order to deal with the simplest and most favorable case, moreover, the coefficients a_k will all be taken as positive; i. e., the detector characteristic will be assumed to be one in which, within the given range, the current increases more and more rapidly with increasing positive voltage.

Suppose, now, that, due to the received signals acting alone, there is a simple harmonic e.m.f. $e \sin p t$ impressed on the detector. The resulting current will be:

$$y = a_1 e \sin p t + a_2 e^2 \sin^2 p t + a_3 e^3 \sin^3 p t + \cdots \tag{3}$$

Remembering that

$$\sin^2 \theta = \frac{1}{2}(1 - \cos 2\theta)$$

$$\sin^3 \theta = \frac{1}{4}(3 \sin \theta - \sin 3\theta)$$

$$\sin^4 \theta = \frac{1}{8}(3 - 4 \cos 2\theta + \cos 4\theta)$$

etc.,

we get:

$$\begin{aligned} y = {} & a_1 e \sin p t + \frac{1}{2} a_2 e^2 (1 - \cos 2 p t) \\ & + \frac{1}{4} a_3 e^3 (3 \sin p t - \sin 3 p t) \\ & + \frac{1}{8} a_4 e^4 (3 - 4 \cos 2 p t + \cos 4 p t) \\ & + \frac{1}{16} a_5 e^5 (10 \sin p t - 5 \sin 3 p t + \sin 5 p t) \\ & + \frac{1}{32} a_6 e^6 (10 - 15 \cos 2 p t + 6 \cos 4 p t - \cos 6 p t) \\ & + \cdots \\ & + \cdots \end{aligned} \tag{4}$$

Grouping the terms of this series according to periodicity, and denoting the current of zero frequency by y_o, that of frequency $\frac{p}{2\pi}$ by y_p, we find:

$$y_o = \frac{1}{2}\left\{ a_2 e^2 + \frac{3}{4} a_4 e^4 + \frac{3 \times 5}{4 \times 6} a_6 e^6 + \frac{3 \times 5 \times 7}{4 \times 6 \times 8} a_8 e^8 + \cdots \right\} \tag{5}$$

$$y_p = \sin p t \left\{ a_1 e + \frac{3}{4} a_3 e^3 + \frac{3 \times 5}{4 \times 6} a_5 e^5 + \cdots \right\} \tag{6}$$

Equations (5) and (6) are general formulas for calculating the rectified and radio frequency currents flowing thru a simple detector circuit of known characteristic. It should be

Digitized by Google

noted that these formulas do not depend on any of the assumptions we have made regarding the shape of the detector characteristic.

Suppose now, to fix the ideas, that ten terms of our series (1) are sufficient to represent the detector characteristic. The last term of the bracketed expression in (5) will then be

$$\frac{3\times5\times7\times9}{4\times6\times8\times10}\,a_{10}\,e^{10}=0.492\,a_{10}\,e^{10};$$

and the last term of the bracket in (6) will be $0.492\,a_9\,e^9$. Since the coefficients a_k are positive, we get, therefore, the following inequalities:

$$a_2\,e^2+a_4\,e^4+\cdots+a_{10}\,e^{10}>a_2\,e^2+\frac{3}{4}\,a_4\,e^4+\cdots+0.492\,a_{10}\,e^{10}$$
$$>0.492\,(a_2\,e^2+a_4\,e^4+\cdots+a_{10}\,e^{10})$$

$$a_1\,e+a_3\,e^3+\cdots+a_9\,e^9>a_1\,e+\frac{3}{4}\,a_3\,e^3+\cdots+0.492\,a_9\,e^9$$
$$>0.492\,(a_1\,e+a_3\,e^3+\cdots+a_9\,e^9).$$

Introducing now our assumption regarding the shape of the characteristic, i. e., the relation (2), it follows that the brackets in (5) and (6) must be of the same order of magnitude. Hence, indicating the amplitude of y_p by Y_p, we may write, as a rough approximation:

$$y_o=\frac{1}{2}\,Y_p\ \text{(roughly)} \qquad (7)$$

For the case of the "perfect" rectifier, on the other hand, we found $\quad y_o=\frac{2}{3}\,Y_p$ approximately.

Thus, the widely different methods of analysis give results of the same order of magnitude, and since, from our conception of an "approximate" rectifier, we should except this to be the case from physical reasoning, the comparison affords an excellent check on the mathematical deductions

Turning now to the behavior of the heterodyne method when used in conjunction with an "approximate" rectifier, let there be a local e.m.f. $E \sin q\,t$ impressed on the detector, and let this be large in comparison with the received e.m.f. $e \sin pt$. The voltage v in series (1) now becomes $E \sin q\,t+e \sin p\,t$. In the binomial expansion of the expressions $(E \sin q\,t+e \sin p\,t)^n$, two terms give a sufficiently close approximation, since $\frac{e}{E}$ is as-

Digitized by Google

sumed small. There results, therefore, for the current in this case:

$$
\begin{aligned}
y = a_1 & (E \sin q t + e \sin p t) \\
& + a_2 (E^2 \sin q t + 2 E e \sin p t \sin q t) \\
& + a_3 (E^3 \sin^3 q t + 3 E^2 e \sin^2 q t \sin p t) \\
& + a_4 (E^4 \sin^4 q t + 4 E^3 e \sin^3 q t \sin p t) \\
& + \cdots \cdots \cdots \\
& + \cdots \cdots \cdots
\end{aligned} \tag{8}
$$

Expanding the terms $\sin^k q t$ and $\sin^{k-1} q t \sin p t$ by well known or easily derived formulas into polynomials involving multiple angles, we get:

$$
\begin{aligned}
y = a_1 & \{E \sin q t + e \sin p t\} \\
& + a_2 \left\{ \frac{1}{2} E^2 (1 - \cos 2 q t) - E e [\cos (q+p) t - \cos (q-p) t] \right\} \\
& + a_3 \left\{ \frac{1}{4} E^3 (3 \sin q t - \sin 3 q t) \right. \\
& \qquad \left. + \frac{3}{4} E^2 e [\sin (2q-p) t - \sin (2q+p) t + 2 \sin p t] \right\} \\
& + a_4 \left\{ E^4 \left(\frac{3}{8} - \frac{1}{2} \cos 2 q t + \frac{1}{8} \cos 4 q t \right) \right. \\
& \qquad + E^3 e \left[\frac{3}{2} \cos (p-q) t - \frac{3}{2} \cos (p+q) t \right. \\
& \qquad \qquad \left. \left. - \frac{1}{2} \cos (3 q - p) t + \frac{1}{2} \cos (3 q + p) t \right] \right\} \\
& + \cdots \cdots \cdots \\
& + \cdots \cdots \cdots
\end{aligned} \tag{9}
$$

Grouping all the terms of frequency $\frac{1}{2\pi}(p-q)$ under the head y_{p-q}, and those of frequency $\frac{1}{2\pi} p$ under the head y_p, there results:

$$
y_{p-q} = \left\{ a_2 E + \frac{3}{2} a_4 E^3 + \frac{3 \times 5}{2 \times 4} a_6 E^5 + \frac{3 \times 5 \times 7}{2 \times 4 \times 6} a_8 e^7 + \cdots \right\} e \cos (p-q) t \tag{10}
$$

$$
y_p = \left\{ a_1 + \frac{3}{2} a_3 E^2 + \frac{3 \times 5}{2 \times 4} a_5 E^4 + \frac{3 \times 5 \times 7}{2 \times 4 \times 6} a_7 E^6 + \cdots \right\} e \sin p t \tag{11}
$$

Equations (10) and (11) are independent of any of the assumptions we have made regarding the shape of the detector

Digitized by Google

characteristic, and are, therefore, general formulas for calculating the beat frequency and received radio frequency currents flowing thru a known heterodyne detector circuit, when the local E.M.F. is large in comparison with that receiver.

Again supposing that ten terms of the series are sufficient, the last term of the bracket in (10) becomes $2.46\,a_{10}\,E^9$, and of that in (11), $2.46\,a_9\,E^8$. Hence there results the inequalities:

$$a_2E+a_4E^3+\quad\cdots\quad+a_{10}E^9<a_2E+\frac{3}{2}a_4E^3+\quad\cdots\quad+2.46a_{10}E^9$$
$$<2.46\,(a_2E+a_4E^3+\quad\cdots\quad+a_{10}E^9),\qquad(12)$$

$$a_1+a_3E^2+\quad\cdots\quad+a_9E^8<a_1+\frac{3}{2}a_3E^2+\quad\cdots\quad+2.46\,a_9E^8$$
$$<2.46\,(a_1+a_3E^2+\quad\cdots\quad+a_9E^8).\qquad(13)$$

Also, from (2) we get

$$a_1+a_3E^2+a_5E^4+\quad\cdots\quad=a_2E+a_4E^3+a_6E^5+\quad\cdots\quad+\frac{\Delta}{E}.\qquad(14)$$

And since the slope of the curve of Figure 4 is small at the origin, $\frac{\Delta}{E}$ will be a small quantity and $a_1+a_3E^2+\ \cdots$ will therefore be nearly equal to $a_2\,E+a_4E_3+\ \cdots$. From (12), (13), and (14) it follows, therefore, that the brackets in (10) and (11) must be of the same order of magnitude. Hence, denoting the amplitude of y_p by Y_p and that of y_{p-q} by Y_{p-q}, we may write, as a rough approximation,

$$Y_{p-q}=Y_p\qquad\text{(roughly)}.\qquad(15)$$

While we have used a relatively small number of terms of the series (1) to get the result (15), the truth thereof would not be affected even if it were necessary to use many more terms. And we may be sure that in all practical cases the rectifier characteristic can be quite accurately specified by comparatively few terms.

A comparison of (15) and (7) shows that for a given Y_p, i. e., for a given amount of received frequency energy in the detector circuit (which is the only fair basis of comparison), the heterodyne method gives roughly twice as much audible frequency current and hence four times as much energy in the response as the "breaking up" methods give, when the detector is an "approximate" rectifier. In this sense, the four-fold amplification of the heterodyne method has once more been demonstrated, but *only* in this sense. For, inasmuch as the received frequency energy abstracted from the oscillatory circuit must

Digitized by Google

be but a small fraction of the total received energy, the result (15) proves that *no matter how large the local heterodyne current may be, the energy in the response must always be less than the energy in the signal.*

The assumption in this analysis of the "approximate" rectifier characteristic of Figure 4 brings out the best that both methods are capable of. In general, however, practical rectifiers do not have as rapid a curvature at the origin as we have assumed here, i. e., they rectify large currents much better than small. Hence the departures of practical characteristics from condition (2) will lessen the effectiveness of the "breaking up" methods far more than that of the heterodyne method. It is for this reason that considerably more than a four-fold amplification is obtained by the heterodyne method, as was brought out very clearly by Mr. Armstrong in his paper. In short, the real advantage of the heterodyne method, aside from the production of a musical tone, lies in the more efficient use of the detector characteristic than is possible without it.

The results contained herein do not reflect any discredit whatever on the heterodyne principle itself, but only upon those theories which purport to show that more could be done therewith than the laws of nature would allow.

SUMMARY: In the case of a simple receiving system it is shown that even with a "perfect" rectifier, as defined, there is more high-frequency energy in the detector circuit than is associated with the rectified current. Also, with a "perfect" rectifier it is shown that the heterodyne method gives just four times the energy in the response as the "breaking up" methods give, irrespective of the amplitude of the local E. M. F.

"Approximate" rectifiers are defined. General formulas are derived for calculating the rectified current and the received radio frequency current flowing in a simple detector circuit of known characteristic; also, general formulas for calculating the beat frequency current and the received radio frequency current in the case of the heterodyne, when the local E. M. F. is larger compared with that received. From these formulas, and from the definition of an "approximate" rectifier, it is shown that the energy in the response must always be less than the energy in the signal.

Digitized by Google

NOTES ON A NEW METHOD FOR THE DETERMINATION OF THE MAGNETIC FLUX DENSITY AND PERMEABILITY*

By

August Hund

(Assistant-Professor in the Department of Physics and Electrical Engineering, University of Southern California, Los Angeles, California)

The following is an outline of a new method for determining the flux density, i. e., number of lines of magnetic induction per unit cross section, up to any desired frequency. The same arrangement may also be conveniently used for obtaining the magnetic permeability and for investigating the total loss of a coil containing a ferro-magnetic core, or the core and copper losses separately.

Principle and Theory of the Method—Explanation of the Arrangement

The suggested arrangement is shown in Figure 1 and is based on the application of a differential system, which has been recently described by the author.[1] One differential branch contains the test sample which has a definite coefficient of self-induction, L_x, for a particular current at a fixed frequency. The test sample is investigated by means of balancing its effect against a standard variable self induction, L_s, (variometer, air-core coils) in series with a non-inductive resistance r.

The performance of such a differential system is briefly as follows: When the currents in the two branches of the system are equal in effective value and in phase, their inductive effects on the secondary coil of the differential transformer will exactly neutralize each other, and no voltage will be induced in the coil. This is based on the assumption that the two primary coils, P_1 and P_2, are symmetrically placed with reference to the secondary coil, S, and have exactly the same number of turns which are wound in opposite directions. Any kind of alternating cur-

* Received by the Editor, October 1, 1916.

[1] A. Hund, "Electrical World," May 22, 1915; reprinted in "London Electrician," August 27, 1915.

rent detector connected across the terminals of the secondary coil will then give a no-current indication when the currents in P_1 and P_2 are equal and in phase.

A no-current adjustment is established when the coefficient of self-induction of the variometer is equal to the effective coefficient of self induction of the test coil and when the effective resistance of the test coil is exactly balanced by the resistance

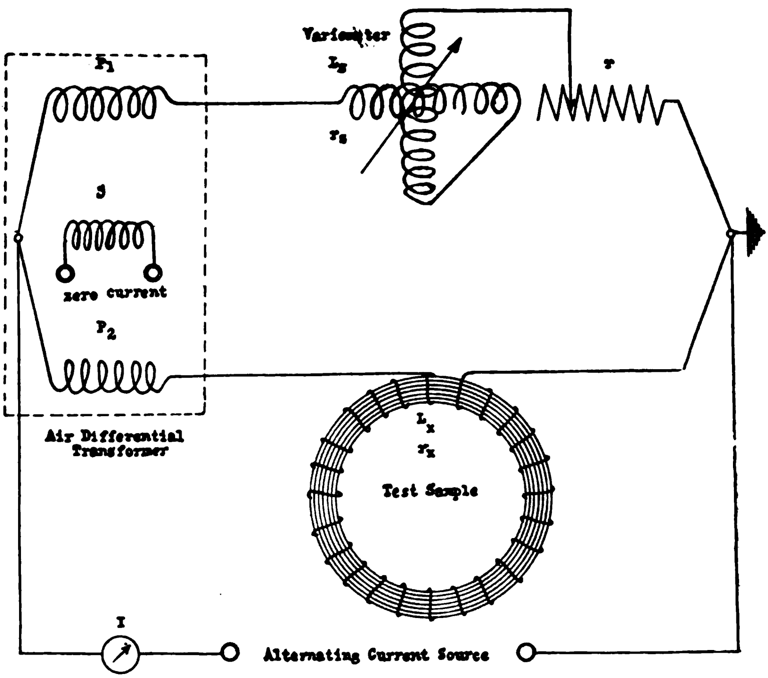


FIGURE 1

of the variometer and the series resistance r. An absolute disappearance of the differential field, however, can generally not be obtained since the wave form in the one branch is somewhat distorted due to the presence of the ferro-magnetic substance. In most practical cases, however, the minimum of the differential field can be very readily and accurately detected. For very precise measurements, it is advantageous to insert a condenser in series with the indicator in the secondary circuit of the differential transformer and tune this circuit to resonance with the required frequency. (This is especially recommended at higher

Digitized by Google

frequencies since a tuning is then readily obtainable.) For frequencies up to about 2,000 cycles, a Wien vibration galvanometer may be used as a current indicator, and the condenser may accordingly be dispensed with.

Derivation of the Expression of the Maximum Flux Density

When the ferro-magnetic core of a coil is exposed to an alternating flux of maximum value, Φ_{max}, the total change in the lines of induction, which go thru the cross sectional area of the iron core, during one half wave, is from zero to Φ_{max} and back to zero, i. e., a total change of $2\,\Phi_{max}$. When f denotes the number of cycles per second and T the corresponding, period, the average rate of change is $\dfrac{2\,\Phi_{max}}{\frac{T}{2}}$. Hence the average induced voltage per each turn of the coil is

$$E_{av} = 4\,f\,\Phi_{max}\,10^{-8} \text{ volts} \tag{1}$$

and the effective value for N turns is equal to

$$E = 4\,F\,f\,N\,\Phi_{max}\,10^{-8} \text{ volts} \tag{2}$$

where F denotes the form factor of the voltage wave, i. e., the ratio of effective value to average value. In case the flux traversing the core follows a sine law, the instantaneous value of it at any time, t, is defined as

$$\Phi_t = \Phi_{max}\,sin\,(2\,\pi\,f\,t)$$

The form factor F as determined according to the above definition is

$$F = \frac{\sqrt{\dfrac{2}{T}\displaystyle\int_o^{\frac{T}{2}} e^2\,d\,t}}{\dfrac{2}{T}\displaystyle\int_o^{\frac{T}{2}} e\,d\,t} = \frac{\dfrac{E_{max}}{\sqrt{2}}}{\dfrac{2\,E_{max}}{\pi}} = 1.111$$

and equation (2) becomes

$$E = 4.44\,f\,N\,\Phi_{max}\,10^{-8} \text{ volts} \tag{3}$$

When this expression is applied to the arrangement under discussion and the maximum flux density, B_{max}, is introduced, we find the expression for the induced E. M. F. of the test sample as

$$E = 4.44\,f\,N\,S\,B_{max}\,10^{-8} \text{ volts} \tag{4}$$

in which relation S stands for the cross sectional area of the

Digitized by Google

iron core. Now let the two inductances, L_x and L_s, be adjusted to the same value; i. e., first, adjustment of phase, and the resistance, r, regulated until the indicator of the differential transformer shows no effect whatever, and second, adjustment of amplitude. Then we may write[2]

$$4.44 f N S B_{max} 10^{-8} = 2 \pi f L_s \frac{I}{2} \qquad (5)$$

which leads to

$$B_{max} = 0.7075 \frac{L_{s\,(henrys)}}{N S_{(cm.)^2}} I_{(amps.)} 10^8 \quad \text{lines of induction per square centimeter} \qquad (6)$$

the expression for the maximum flux density in terms of L_s as read on the variometer; I, as measured by the ammeter in the main branch of the differential arrangement; N, the number of turns of the test sample; and, S, the cross sectional area of the iron core.

Determination of the Resultant Field Intensity H_{max} and Magnetic Permeability μ

One way of exploring the magnetic properties of a ferromagnetic substance by means of this method is to use a circular ring on which is uniformly wound a coil of wire of comparatively low resistance. Then the maximum magnetizing force, H_{max}, is defined by the formula[3]

$$H_{max} = \frac{4\pi}{10} \sqrt{2} \frac{N I_{m\,(amps)}}{l_{cm}} \quad \text{gilberts per centimeter} \qquad (7)$$

where I_m is the magnetizing component of the effective current traversing the coil of the sample, N the number of turns in the coil, and l the mean length of the magnetic path in centimeters. It is to be borne in mind that this equation holds only approximately when the diameter of the ring is large as compared with the diameter of the cross section. Suppose that in Figure 2 L_x and r_x denote the effective coefficient of self induction and apparent resistance of the sample and that they are exactly balanced by L_s and $(r_s + r)$; that is, the self induction of the variometer, the resistance of it, and the additional balance resistance r. The vector diagram of Figure 3 then shows the voltage relations in the test coil and objects used for comparison. In this diagram V denotes the effective terminal pressure of the test sample and ϕ the phase difference between V and the branch current $I/2$. If the ohmic resistance of the sample, for direct current, is denoted by r_x' and if Δr_f represents the increase in

[2] This is only approximately true since the resistance adjustment changes the phase also to a certain extent.

[3] 1 gilbert = 0.79578 ampere-turn.

Digitized by Google

resistance due to skin effect at the frequency f, and since the increase of resistance due to hysteresis and eddy current losses is given by the term

$$\frac{\text{total iron losses}}{\left(\frac{1}{2}\right)^2}$$

the apparent resistance, r_x, of the sample is defined by

$$r_x = r_x' + \Delta\, r_f + \frac{W_c}{\left(\frac{I}{2}\right)^2}$$

$$= r_s + r \qquad (8)$$

where W_c stands for the total core loss in the ferro-magnetic substance. To equate r_x to the quantity $(r_s + r)$ is correct if

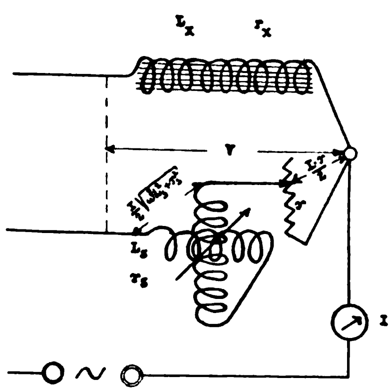


FIGURE 2

we assume that the wire used for the variometer shows no appreciable skin effect, so that its direct current resistance $r' = r$ is equal to the alternating current resistance r''. Within the range of the very high (radio) frequencies such an assumption can not be made, even if ideal twisted wires or ribbons are used, such as described by the author in a previous publication,[2] and the high frequency resistance of the variometer is to be determined by the well known methods if a calibration curve is not available. The magnetizing current I_m which is to be introduced in the equation (7) can be expressed in terms of the effective

[4] A. Hund, "Arbeiten aus dem Elektrotech. Institut der Technischen Hochschule, Karlsruhe," Volume III.

Digitized by Google

current thru the test sample. For the balanced differential system we obtain

$$I_m = \frac{I}{2} \sin \phi \qquad (9)$$

This equation is based on the assumption that the resistance of the windings of the sample is small as compared with the inductive reactance, a requirement which is easily fulfilled, espe-

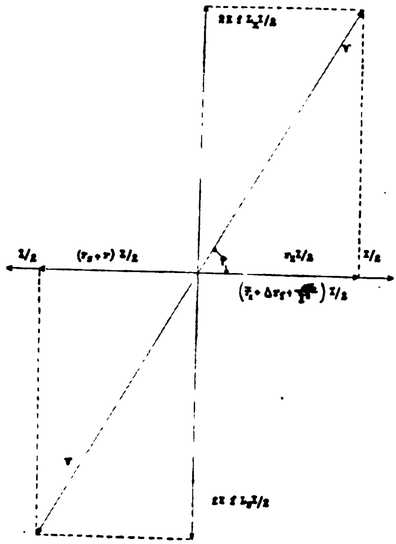


FIGURE 3*

cially at higher frequencies where the wattless components usually become very pronounced. The proof of this approximation may be readily seen from the following consideration:

The total iron loss of the test sample produces an increase in current and decrease in phase displacement, ϕ, between impressed voltage and current under the conditions of constant terminal voltage. That is, the iron acts like a secondary circuit which is coupled to the coil of the sample. This fact is shown in Figure 4 where $A\,B\,C$ denotes the impedance triangle for the sample coil without iron, for which

$\overline{A\,B} = 2\,\pi f L_x$, the inductive reactance

$\overline{B\,C} = r_x'' = r_x' + \Delta\, r_f$, the effective ohmic resistance at the frequency f and

* Wherever an r with a dash (—) over it appears in a figure, it corresponds to r' in the text; similarly an r with a cycle mark (∿) over it corresponds to r'' in the text.

Digitized by Google

$\overline{AC} = Z_x$

$= \sqrt{(2\pi f L_x)^2 + r_x''^2}$, the resistance operator of the coil.

The impedance triangle goes over into the triangle $A'BC'$ for the same terminal voltage when the iron core is added, which represents the true conditions of the sample. In this case we have

$$\left.\begin{array}{l} \overline{A'B} = 2\pi f (L_x - \Delta L_x), \text{ the inductive reactance} \\ \overline{BC'} = r_x = r_x'' + \dfrac{W_c}{\left(\frac{I}{2}\right)^2}, \text{ the apparent ohmic resistance} \\ \overline{A'C'} = Z_x' \\ \quad = \sqrt{\left[2\pi f (L_x - \Delta L_x)\right]^2 + \left[r_x'' + \dfrac{W_c}{\left(\frac{I}{2}\right)^2}\right]^2}, \\ \qquad \text{the resistance operator of the coil} \end{array}\right\} \begin{array}{c}\text{for a}\\ \text{certain}\\ \text{current of}\\ \text{definite}\\ \text{frequency.}\end{array}$$

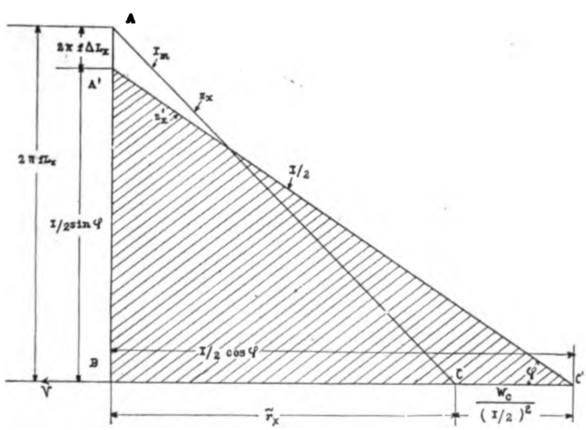


FIGURE 4

The angle $A'C'B$ represents the actual displacement of phase between impressed voltage and current traversing the coil. A little further analytical reasoning will show that the decrement in self inductance due to the presence of the ferro-magnetic substance is given by the expression

$$\Delta L_x = \frac{(2\pi f M)^2 L_2}{r_2^2 + (2\pi f L_2)^2} \tag{10}$$

Digitized by Google

and the increment in resistance due to the presence of the ferro-magnetic substance by

$$\frac{W_c}{\left(\frac{I}{2}\right)^2} = \frac{(2\pi f M)^2 r_2}{r_2^2 + (2\pi f L_2)^2} \tag{11}$$

in which case we imagine the iron core to be substituted by a secondary circuit of self inductance L_2 and ohmic resistance r_2. M denotes then the mutual inductance between the coil of the test sample and the fictitious turns of the secondary. We know from the theory of alternating currents that the current triangle is similar to the impedance triangle; which, when applied to our case, means that Figure 4 simultaneously represents the current relations. The scale, of course, would have to be properly selected. Thus the shaded triangle, the case where a ferro-magnetic substance is present, is as follows:

$$\left.\begin{array}{l} A'B = \frac{I}{2}\ \sin\phi, \text{ the wattless component} \\ \overline{BC'} = \frac{I}{2}\ \cos\phi, \text{ the watt component} \end{array}\right\} \begin{array}{c}\text{of the current} \\ \text{in the coil}\end{array}$$

$\overline{A'C'} = \frac{I}{2}$, the actual current passing thru the coil of the sample and which is determined from the ammeter reading in the main branch of the differential system.

The triangle $A\,B\,C$ represents the vector diagram for the currents when no iron core is present and the hypothenuse denotes the magnetizing current I_m which is utilized in equation (7) for the evaluation of the magnetizing force H_{max}.

Returning to equation (10) we learn that ΔL_x is only a very small quantity when the term, r_2^2, in the fictitious secondary circuit is large as compared with the term $(2\pi L_2)^2$. This is true in our case to a fair degree of approximation when we assume that the eddy currents are induced in a well subdivided iron core, such as is usually employed in alternating current practice at higher frequencies. With this assumption, the point A and A' may be thought of as coinciding, which leads to a current diagram such as is shown in Figure 5. The base B C' represents, to a certain scale the total power input for the test sample containing a ferro-magnetic core since $C\,C'$ denotes the input due to hysteresis and eddy current loss, and $B\,C$ the input due to copper loss in the turns of the sample. If the resistance of the sample is kept small in comparison with the inductive reactance, as indicated in Figure 5, the magnetizing current,

Digitized by Google

I_m, is only a little smaller than the wattless component of the true and measurable coil current. This means that for a thinly laminated iron core and using the so-called ideally twisted wire[5] in the test coil of rather low resistance and comparatively high self inductance, the sine component of the branch current passing

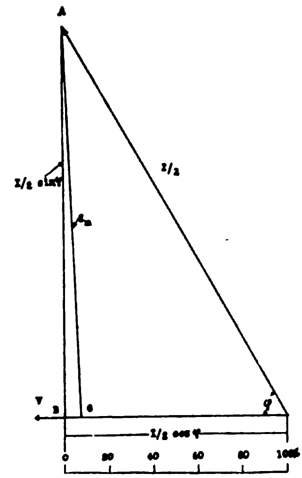


FIGURE 5

thru the sample denotes to a fair degree of approximation the magnetizing current I_m. Returning to equation (9) we find there the magnetizing force, H_{max}, and the magnetic permeability, μ, by the following procedure:

$$\sin\phi = \frac{2\pi f L_x}{\sqrt{r_x^2 + (2\pi f L_x)^2}}$$

$$= \frac{2\pi f L_s}{\sqrt{(r_s + r)^2 + (2\pi f L_s)^2}}$$

then the magnetizing current becomes

$$I_m = \frac{I}{2} \cdot \frac{2\pi f L_s}{\sqrt{(r_s + r)^2 + (2\pi f L_s)^2}} \tag{10}$$

and according to equation (7) the maximum magnetizing force is defined as

$$H_{max} = 5.57 \frac{N f L_{s\,(henry)} \cdot I_{(amps)}}{l_{(cm)} \sqrt{(r_{s\,(ohm)} + r_{(ohm)})^2 + 2\pi f L_{s\,(henry)})^2}} \text{ gilberts per centimeter} \tag{11}$$

[5] "Litzendraht."

Digitized by Google

and the magnetic permeability is given by the relation

$$\mu = \frac{B_{max}}{H_{max}}$$

$$= 1.27 \frac{l_{(cm)} \sqrt{(r_{s\,(ohm)} + r_{(ohm)})^2 + (2\pi f L_{s\,(henry)})^2}}{N^2 \cdot S_{(cm)} \cdot f} 10^7 \qquad (12)$$

When the wave length, λ, is introduced, as is often customary within the range of radio frequencies, the maximum magnetizing force and magnetic permeability may be determined by the following relations[6]:

$$H_{max} = 16.71 \frac{N \cdot L_{s\,(henry)} I_{(amps)}}{\lambda_{(m)} l_{(cm)} \sqrt{(r_{s\,(ohm)} + r_{(ohm)})^2 + \left(\frac{6\pi \cdot 10^8 L_{s\,(henry)}}{\lambda_{(m)}}\right)^2}} \times 10^8$$

gilberts per centimeter (11*a*)

and

$$\mu = 42.33 \frac{\lambda_{(m)} l_{(cm)} \sqrt{(r_{s\,(ohm)} + r_{(ohm)})^2 + \left(\frac{6\pi \cdot 10^8 L_{s\,(henry)}}{\lambda_{(m)}}\right)^2}}{N^2 S_{(cm)^2}} \times 10^{-3} \qquad (12a)$$

We therefore see that for a standard test ring of given cross sectional area, length of magnetic path and number of turns, the maximum flux density, B_{max}, the maximum resultant field intensity, H_{max}, and the permeability, μ, can be calculated from observed data by means of the three following formulae:

$$B_{max} = k_1 L_{s\,(henry)} I_{(amps)}$$ lines of induction per square centimeter (13)

$$H_{max} = k_2 \frac{f L_{s\,(henry)} I_{(amps)}}{Z_{(ohms)}}$$ gilberts per centimeter (14)

$$\mu = k_3 \frac{z_{(ohms)}}{f} \qquad (15)$$

where z is equivalent to the resistance operator of the test sample and the constants k_1, k_2, and k_3 of a definite dimensioned sample are given by the relations:

$$\left.\begin{aligned} k_1 &= \frac{0.7075 \times 10^8}{N . S_{(cm)^2}} \\ k_2 &= 5.57 \frac{N}{l_{(cm)}} \\ k_3 &= 1.27 \frac{l_{(cm)}}{N^2 S_{(cm)^2}} 10^7 \end{aligned}\right\} \qquad (16)$$

[6] In above formulas, both meters and centimeters are purposely employed, since the wave meters are usually calibrated in meters and the length of the magnetic path is generally measured in centimeters. To express also the self induction in the C. G. S. system was not done since most of the commercial variometers are calibrated in practical units.

Digitized by Google

A few concluding remarks on the true magnetizing current, I_m, such as utilized for the calculation of the magnetizing force, are given here, before the determination of the core losses is discussed. Such considerations may not be entirely new, altho it seems worth while to add a more detailed analysis in direct application to the differential system, and to derive other expressions with which to calculate the magnetizing force and the permeability.

One should first clearly distinguish between exciting current and magnetizing current, since in ordinary engineering discussions both expressions are often used interchangeably to denote the same quantity, namely, the no-load current of the transformer and the feeding current of a choke coil, respectively. Exciting current of the test sample is the total flow of electricity that passes thru the coil. It is denoted by $I/2$ for the balanced differential system, and is obtained from the ammeter reading of the main branch of the arrangement. This current includes that consumed as Joulean heat losses in the windings of the sample, and also for supplying the losses due to hysteresis and eddy currents. The exciting current may therefore be split up into an energy component, determined by the total loss which is in the vectorial direction of the terminal pressure, V, and into the magnetizing component, I_m, which is in the vectorial direction of the magnetic induction, B, i. e., wattless. Now, if the flux density of the ferro-magnetic medium is within the range of the straight part of the magnetization curve, the magnetizing current, I_m, will vary according to a sine law when the flux is sinusoidal. But in case of higher saturations for which the flux density rises beyond the straight part of the saturation curve (for instance, beyond the knee), the magnetizing current becomes distorted. Consequently, the exciting current which a sinusoidal impressed E. M. F. will establish in the turns of our test sample no longer varies according to a sine law. This can be seen from Figure 6 where the instantaneous current values, $i/2$, of the test coil, such as have been obtained from the hysteresis loop, are plotted against the time. It is to be noted that the ohmic drop in the winding is considered as being small enough to be neglected in this representation, so that it is possible to assume that the induced E. M. F. is at all times equal and opposite to the impressed terminal voltage, V, of the sample. The figure clearly shows that the exciting current, $i/2$, required to produce a sinusoidal flux density wave is unsymmetrical with respect to its maximum ordinate. The maximum flux density occurs at

Digitized by Google

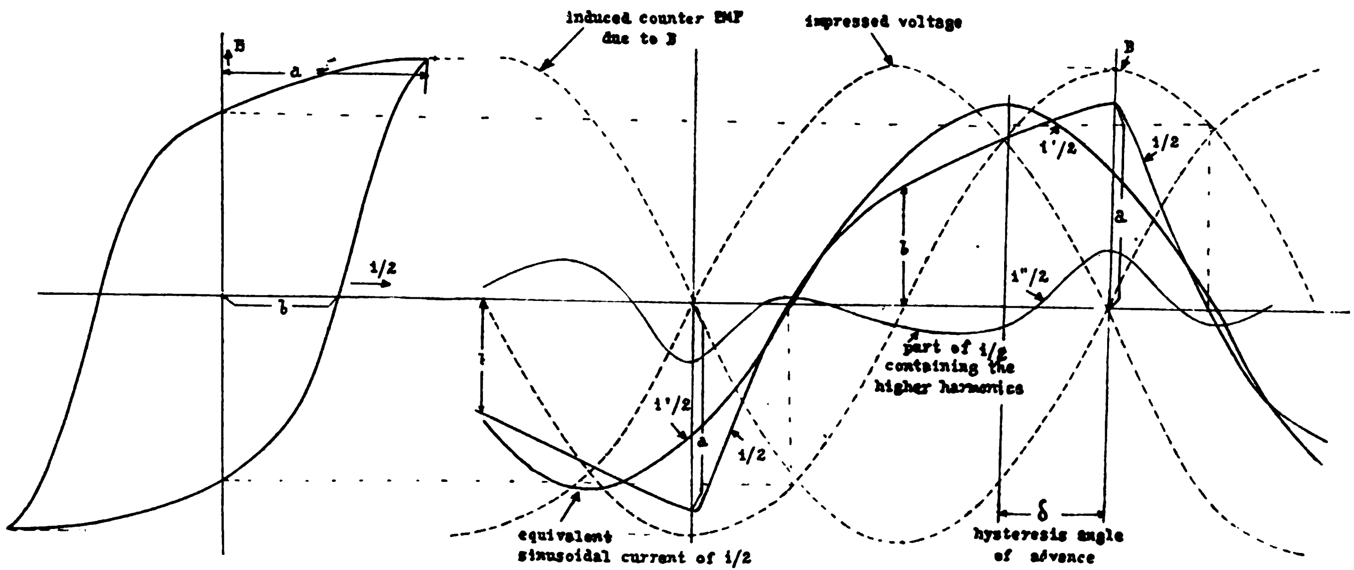


FIGURE 6

Digitized by Google

the same time that the exciting current reaches its maximum; that is to say, this current is 90 time-degrees ahead of the induced E. M. F. and generally about 90 time-degrees behind the impressed voltage, whereas the intersection with the zero line indicates a considerable lead with respect to the zero value of the flux density. The wave of the exciting current of commercial frequency up to the highest frequencies, such as employed in radio telegraphy and telephony, is usually distorted by the presence of higher harmonics of a very pronounced triple harmonic. As is indicated above, the distortion is chiefly due to the magnetizing current, I_m, and is caused on account of the curved part of the B-H curve. With transformers, this distortion is greatly diminished by the load current which, when large enough, makes insignificant the well defined distorting component of the exciting current. In our case, however, where a closed magnetic circuit is often employed, the distortion is very pronounced and an analysis of the exciting circuit is accordingly of interest. One way of studying the distorted exciting current is to split it up into those components which are in phase with the induced E. M. F. (and are often called the hysteresis and power components), and one component 90 time-degrees behind it (that is, in phase with the magnetic induction, B, and representing the magnetizing current). Such a resolution of the exciting current is shown in Figure 7, which represents a typical case. It is readily seen

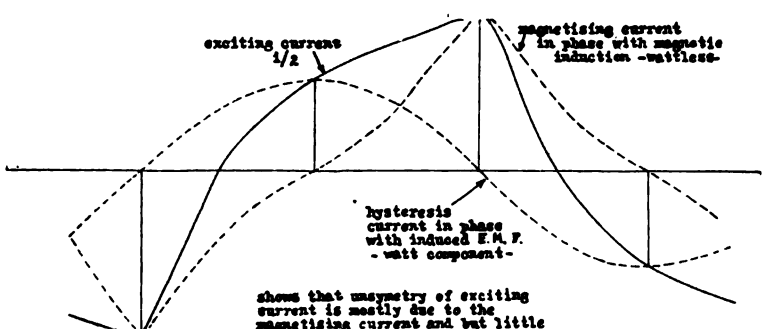


FIGURE 7

that the distortion of the exciting current, such as is obtained from the hysteresis loop, is chiefly influenced by the magnetizing component as a consequence of the non-proportionality of the

Digitized by Google

B-H relation, whereas the hysteresis current wave is a good approximation a sine curve. (The reader who would like to pursue this subject in more detail will find a very interesting treatment in Dr. Steinmetz's "Alternating Current Phenomena.") In Figure 6, the exciting current is, however, resolved into a first harmonic component of the same power and effective value as that of the exciting current curve and into a component containing the higher harmonics. The latter component, which is composed of the higher harmonics, is wattless with respect to the sinusoidal applied voltage of fundamental frequency and consequently the effective watt component, $I'_w/2$, of the equivalent sine wave, $i'/2$, denotes the total power component of the exciting current and is equivalent to I_h, the hysteresis current. The magnetizing current, I_m, is then constituted of the wattless component, $I'_{wL}/2$, of the equivalent sine wave, $i'/2$, and the effective value $I''/2$ of the curve, $i''/2$, containing the higher harmonics, chiefly of triple frequency. This is made plainer by the vector diagram of Figure 8, which shows the construction of the effective value, $I/2$, of the exciting current, $i/2$; which, by assumption, is also equal to the effective value of the equivalent sine curve. The vector, $I/2$, makes the angle, δ, with the true magnetizing current. The same is called the angle of hysteretic phase advance, and denotes the angle by which the first harmonic of the exciting current leads the sinusoidal wave of the flux density, B. The effective value of the measurable coil current of the test sample is therefore given by the relation

$$\frac{I}{2}=\sqrt{\left[\frac{I'_w}{2}\right]^2+\left[\left(\frac{I'_{wL}}{2}\right)^2+\left(\frac{I''}{2}\right)^2\right]^2} \tag{17}$$

and the effective value of the true magnetizing current entering the equation (7) becomes

$$\begin{aligned} I_m &= \sqrt{\left[\frac{I'_{wL}}{2}\right]^2+\left[\frac{I''}{2}\right]^2} \\ &= \sqrt{\left[\frac{I}{2}\right]^2-\left[\frac{I'_w}{2}\right]^2} \end{aligned} \tag{18}$$

which, translated into technical language, states that the power component demagnetizes the iron core. This can be made plainer by drawing the hysteresis component, $-I_h$, equal and opposite to, I_h. Then the vectors, $-I_h$ and $I/2$, constitute the magnetizing current, I_m. The diagram shows furthermore that for zero hysteresis effect, the magnetizing current would be identical with

Digitized by Google

the exciting current, $I/2$, altho the wave would be still unsymmetrical due to the varying permeability, μ.

The power, W_h, dissipated because of the hysteresis can be determined by this method, as is shown in a later paragraph. The effective current $I/2$ is obtained from the ammeter reading of the balanced arrangement and the applied terminal voltage, V, is found from the relation:

$$V=\frac{I}{2}\sqrt{r_x^2+(2\pi f L_x)^2}$$
$$=\frac{I}{2}\sqrt{[r+r_s]^2+[2\pi f L_s]^2} \qquad (19)$$

The magnetizing current is then determined according to the procedure

$$W_h=V\cdot\frac{I}{2}\cos(90-\delta)$$
$$=V\cdot\frac{I}{2}\sin\delta$$
$$=V\cdot\frac{I'_w}{2} \qquad (20)$$

introduced in equation (18)

$$I_m=\sqrt{\left[\frac{I}{2}\right]^2-\left[\frac{W_h}{V}\right]^2} \qquad (21)$$

This equation, however, is based on the assumption that the ohmic drop in the test sample is negligibly small and the losses due to eddy currents are accordingly ignored. The first assumption may be readily satisfied by employing so-called "ideal"-twisted wire of low resistance, while the effect due to eddy currents has to be taken into account, especially when taking readings within the range of radio frequencies. It is known that the eddy currents, like magnetic hysteresis, cause the phase of the current to advance; the angle of which phase advance can be calculated from its sine, which is defined by the ratio of the absolute admittance of the circuit to the eddy current conductance. For well laminated iron cores, the distortion of the current wave may be kept very small, as can be demonstrated by investigating the hysteresis loops of different laminated samples by means of a Bràun tube. The distortion of the hysteresis loop, due to eddy currents, is caused because they act like secondary circuits and consequently their magnetic fields counteract the main field of the coil. For this reason, in the case of a fixed magnetizing force, the total flux density is smaller when eddy currents are

Digitized by Google

present than without it. Hysteresis loops such as were found in the splendid researches of Prof. Max Wien[7] and others show this effect very plainly. Furthermore, the loops show rounded corners and are more inclined to the axis of the magnetizing force at higher frequencies, altho the area of the loop seems to change but little as the frequency increases. Another important in-

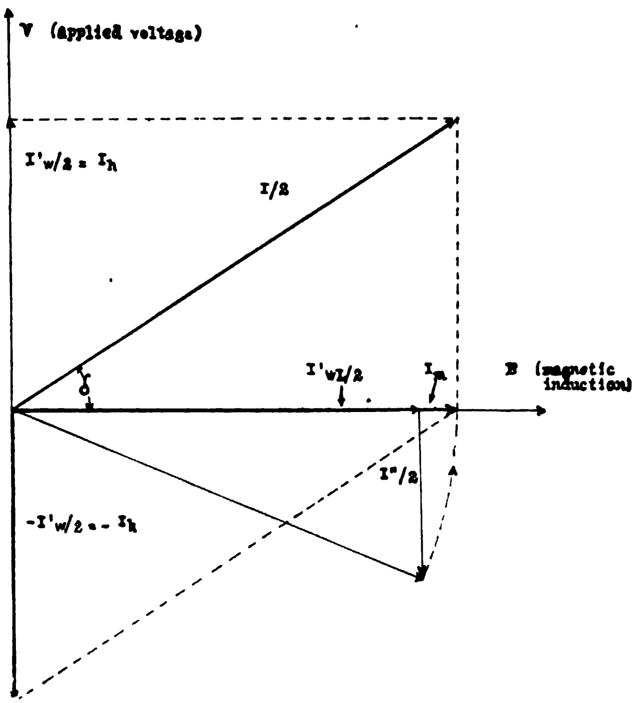


FIGURE 8

fluence of the eddy currents on the hysteresis loss, which is especially pronounced at higher frequencies, is that the lines of magnetic induction are not uniformly distributed over the cross section of the iron core.

Nevertheless, the measurements described in the above paragraph are not any more difficult when the effect of the eddy currents is taken into account; for the flux density wave (and along with it the eddy currents) also follow a sine law with a sinusoidal terminal voltage. The eddy currents simply increase the watt

[7] M. Wien, "Ann. der Physik," 1898.

Digitized by Google

and wattless components of the equivalent sine wave of the exciting current on account of the larger exciting current. This means that the general formula of equation (21) is given by the expression

$$I_m = \sqrt{\left[\frac{I}{2}\right]^2 - \left[\frac{W_c}{V}\right]^2} \tag{22}$$

and, according to a derivation given in a later paragraph, the true magnetizing current may be found from

$$I_m = \sqrt{\left[\frac{I}{2}\right]^2 - \left[\frac{\left(\frac{I}{2}\right)^2 \Delta r_c}{\frac{I}{2}\sqrt{r_x^2 + (2\pi f L_x)^2}}\right]^2}$$

or

$$I_{m\,(amps)} = \frac{I_{(amps)}}{2}\sqrt{1 - \frac{(\Delta r_{c\,(ohm)})^2}{(r_{(ohm)} + r_{s\,(ohm)})^2 + (2\pi f L_{s\,(henry)})^2}} \tag{23}$$

which leads to the expressions

$$H_{max} = 0.8875 \frac{N \cdot I_{(amps)} \sqrt{1 - \frac{(\Delta r_{c\,(ohm)})^2}{(r_{(ohm)} + r_{s\,(ohm)})^2 + (2\pi f L_{s\,(henry)})^2}}}{l_{(cm)}} \text{ gilberts per centimeter} \tag{24}$$

and

$$\mu = 0.798 \frac{l_{(cm)} L_{s\,(henry)} 10^8}{N^2 S_{(cm)^2} \sqrt{1 - \frac{(\Delta r_{c(ohm)})^2}{(r_{(ohms)} + r_{s\,(ohm)})^2 + (2\pi f L_{s\,(henry)})^2}}} \tag{25}$$

We therefore see that for a standard test ring of given cross sectional area, length of magnetic path and number of turns, the maximum resultant field intensity, H_{max}, and the magnetic permeability, μ, can be calculated from observed data by means of the following formulas:

$$H_{max} = k_4 I_{(amps)} \sqrt{1 - \left(\frac{\Delta r_{c\,(ohm)}}{z_{(ohm)}}\right)^2} \text{ gilberts per centimeter} \tag{26}$$

and

$$\mu = k_5 \frac{L_{s\,(henry)}}{\sqrt{1 - \left(\frac{\Delta r_{c\,(ohm)}}{z_{(ohm)}}\right)^2}} \tag{27}$$

where z represents again the resistance operator of the test sample and constants k_4 and k_5 are given by the expressions

$$\left.\begin{aligned} k_4 &= 0.8875 \frac{N}{l_{(cm)}} \quad \text{and} \\ k_5 &= 0.798 \times 10^8 \frac{l_{(cm)}}{N^2 S_{(cm)^2}} \end{aligned}\right\} \tag{28}$$

Digitized by Google

If the magnetic field of a coil is replaced by a ferro-magnetic field, the number of lines of induction is increased, which in turn necessitates an increase in the coefficient of self induction of the coil. Since the flux does not increase as the current traversing the coil on an iron core, the coefficient of self finduction is not a constant for a certain frequency, but is a function of the current. Because the iron core is a consumer of energy, the ohmic resistance of the coil will apparently increase (equation (8)). This means that the quantity, r_x, also depends on the current. The differential arrangement therefore is a ready means to determine the iron losses. The procedure is simply this:

Measure the resistance, r_x', of the test sample without iron by means of direct current. Adjust the resistance of the variometer combination to the same value by regulating the series resistance, r. Then apply the desired high frequency current of a definite frequency, f, to the differential system and increase r in the variometer branch by the quantity, Δr_f; that is, until an amplitude adjustment is attained. It is also advisable simultaneously to balance the phases of the two differential branches by making, $L_s = L_x$, since then the amplitude balance is more easily obtainable under such conditions. The additional resistance, Δr_f, then represents the increase of the ohmic resistance due to skin effect, which produces the additional loss, $\Delta r_f \left(\frac{I}{2}\right)^2$. Now insert the iron core in the coil, adjust the phase by again varying the standard self inductance (that is, until, $L_{s_c} = L_{x_c}$), where L_{x_c} denotes the effective coefficient of self induction of the test coil in the presence of iron for a certain wave length and a definite current value. Then add the resistance, Δr_c, until a complete balance is reached. The quantity, Δr_c, stands then for the increase of resistance due to core loss for a certain current and wave length, which leads to the following relations:

$$\begin{aligned} W_c &= \left[\frac{I}{2}\right]^2 \Delta r_c \\ &= W_h + W_e \\ &= \eta \cdot f v B_{max}^{\alpha} 10^{-7} + \xi f^2 d^2 v B_{max}^{\beta} 10^{-14} \end{aligned} \tag{29}$$

where W_c, W_e, W_h denote: the total core loss, eddy current loss, hysteresis loss in watts, η the hysteresis coefficient, ξ the eddy current coefficient, v the volume of the iron in cm.³ B_{max} the maximum number of lines of induction per cm.,² d the thickness of the iron laminations in cm. The ex-

Digitized by Google

ponents a and β can be determined by observations at different flux densities. The separation of the hysteresis and the eddy current losses may be carried on in the usual way, when observations are taken for the same flux density at two different frequencies, f_1 and f_2, using the following expressions

$$\left.\begin{aligned}\frac{W_{c1}}{f_1} &= \eta\, v\, B^a_{max}\, 10^{-7} + \xi f_1\, d^2\, v\, B^\beta_{max}\, 10^{-14}\\ &= K_1 B^a_{max} + K_2 f_1 B^\beta_{max}\\ &= A + f_1 D\\ \text{and} \quad \frac{W_{c2}}{f_2} &= \eta\, v\, B^a_{max}\, 10^{-7} + \xi f_2\, d^2\, v\, B^\beta_{max}\, 10^{-14}\\ &= K_1 B^a_{max} + K_2 f_2 B^\beta_{max}\\ &= A + f_2 D\end{aligned}\right\} \quad (30)$$

where, A, denotes the hysteresis loss in watts per cycle and, $f \cdot D$, the eddy current loss in watts per cycle. Hence

$$\left.\begin{aligned}A &= \frac{\dfrac{W_{c1} \cdot f_2}{f_1} - \dfrac{W_{c2} \cdot f_1}{f_2}}{f_2 - f_1}\\ &= 0.333..\frac{W_{c1} \cdot \lambda_1^2 - W_{c2} \cdot \lambda_2^2}{\lambda_1 - \lambda_2} \times 10^{-8}\\ \text{and} \quad D &= \frac{\dfrac{W_{c1}}{f_1} - \dfrac{W_{c2}}{f_2}}{f_1 - f_2}\\ &= 0.111..\frac{W_{c1} \lambda_1^2 \lambda_2 - W_{c2} \lambda_1 \lambda_2^2}{\lambda_2 - \lambda_1} \times 10^{-16}\end{aligned}\right\} \quad (31)$$

where the wave length, λ, is again expressed in meters and W_{c1} and W_{c2} in watts.

Practical Hints On a Proper Differential Arrangement—A Discussion of Disturbances and Means of Overcoming Them

As can be seen from the introduction, the similarity and symmetrical arrangement of the two differential coils are a most important feature for the proper design of the transformer, because dissymmetry of the windings affects the inductance and resistance as well as the capacity phenomena of the primary coils with respect to the secondary. When these factors are not absolutely the same for each primary coil the phase of the radio frequency currents will be shifted unequally. All these conditions are complied with by the application of the so-called "ideal"-twisted wires. Approximately six turns in each primary coil with a diameter of about six inches (15 cm.) are recommended,

Digitized by Google

in order to avert any unnecessarily large transformer losses. The same number of turns may be conveniently used for the secondary coil of the air transformer altho it is advisable to compute the number required for a particular zero current indicator.

Other disturbances present themselves because of the effect of the magnetic fields of the test sample and variometer in the secondary circuit of the transformer, and sometimes it is entirely impossible to cause the effects of the differential field to disappear completely. These influences are, however, overcome by arranging the test and comparison apparatus in such a way as to make their induction upon the transformer and secondary circuit a minimum. By choosing long leads on the one side (connecting to the transformer) the above-mentioned disturbances are practically eliminated.

Furthermore, it should be noted that inductive and capacity effects of the different parts of the arrangement with respect to each other are very pronounced within the range of radio frequency currents such as employed in radio telegraphy and telephony. Numerous investigations have shown that an accurate equalization of the differential system is practically impossible without extreme precautions. For this reason a double cable (bifilar) enclosed in a grounded brass tube was used for all leads such as the mains which connect the apparatus to the radio frequency source and the leads connecting the zero current indicator with the differential transformer. One joint of the differential arrangement is also grounded (Figure 1) in order to cut down unnecessary leakage currents.

Further, it is interesting to study the case in which the resistance used for compensating the loss of the coil shows appreciable self induction and capacity effects. Consider the differential arrangement of Figure 9 as follows: The inserted series resistances, r_1 and r_2, each had a certain amount of self induction, ΔL_1 and ΔL_2, as well as a definite value of capacity, ΔC_1 and ΔC_2. Comparing the test sample with the variometer and these resistances, we obtain for the balance condition

$$r_x+r_2+j\left\{\omega\,[L_x+\Delta L_2]-\frac{1}{\omega\,\Delta C_2}\right\}$$

$$=r_s+r_1+j\left\{\omega\,[L_s+\Delta L_1]-\frac{1}{\omega\,\Delta C_1}\right\} \quad (32)$$

n [illegible]

$$r_x-r_s=r_1-r_2 \quad (33)$$

[illegible] part gives the ratio

$$[illegible]\frac{}{L_s}\left[(\Delta L_1-\Delta L_2)+\frac{1}{\omega^2}\left(\frac{\Delta C_1-\Delta C_2}{\Delta C_1\cdot\Delta C_2}\right)\right] \quad (34)$$

Digitized by Google

which shows that the difference of self induction, $\Delta L_1 - \Delta L_2$, has to be small in comparison with the effective self induction of the test sample. This condition is practically satisfied by the use of short length of manganin or constantin wire for the resistances r_1 and r_2. It is seen from equation (33) that the measurement of the difference of the resistance of test sample and variometer is not affected by any inductive or capacity effects of the

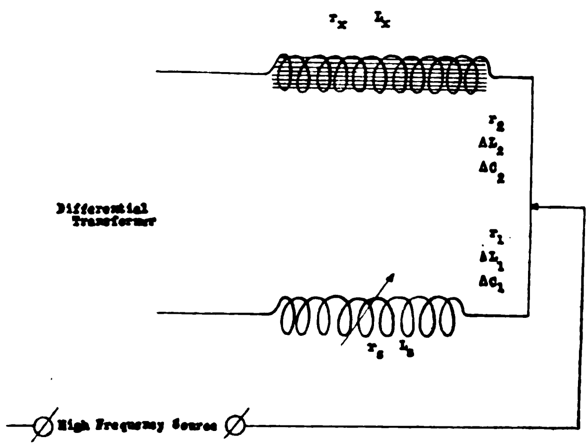


FIGURE 9

inserted balancing resistances, r_1 and r_2. This is an essential advantage of the differential method in comparison with the usually applied bridge arrangements, for the same inductive and capacity influences of the resistance introduce considerable errors at higher frequencies unless the bifilar bridge of Giebe is applied. The latter requires, however, an exact knowledge of the capacity and inductance of the leads, and is hardly available for measurements such as are met with in radio telegraphy. The influence of inductive effects of the resistances upon the loss adjustment, in case a bridge arrangement were used, may be seen fron Figure 10 and the following deductions. We then have as a general condition of balance

$$\frac{r_x+j\,\omega\,L_x}{r_s+j\,\omega\,L_s}=\frac{r_2+j\,\omega\,\Delta\,L_2}{r_1+j\,\omega\,\Delta\,L_1} \tag{35}$$

and separating the real and imaginary parts,

$$r_x\,r_1-r_s\cdot r_2=\omega^2\left[L_x\,\Delta\,L_1-L_s\,\Delta\,L_2\right] \tag{36}$$

Digitized by Google

$$L_x r_1 - L_s r_2 = r_s \Delta L_2 - r_x \Delta L_1 \tag{37}$$

or

$$\frac{r_x}{r_s} = \frac{r_2}{r_1} + (2\pi f)^2 \left[\frac{L_x \Delta L_1 - L_s \Delta L_2}{r_1 r_s}\right]. \tag{38}$$

$$\frac{L_x}{L_s} = \frac{r_2}{r_1} - \left[\frac{r_x \Delta L_1 - r_s \Delta L_2}{L_s r_1}\right] \tag{39}$$

Equation 38 shows clearly that the resistance adjustment is considerably affected at higher frequencies when inductive effects

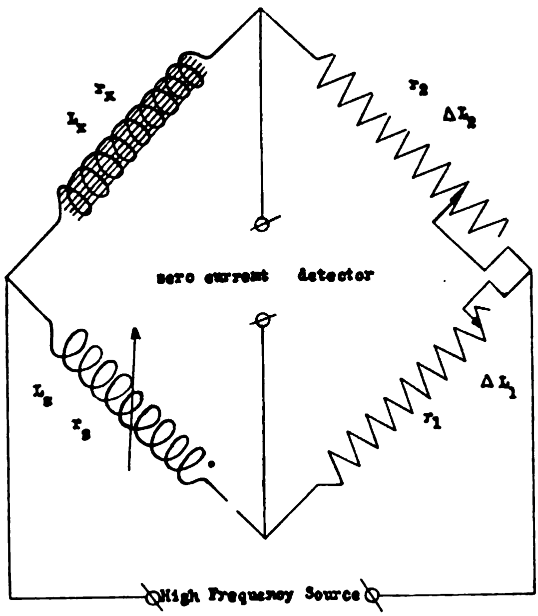


FIGURE 10

of r_1 and r_2 present themselves. Moreover, the bridge method is not advantageous since four branches act inductively on each other. Furthermore, three terms are to be varied for balance instead of only two and the protection of the detector circuit would cause grave difficulties.

The ordinary thermo-couple arrangement and barreter system are convenient expedients as zero current detectors, altho for very delicate readings the thermo-cross bridge is to be recommended.

Before concluding, it might be of interest to investigate somewhat the effects of the disturbing capacity with respect

Digitized by Google

to the body of the observer and the like. For this purpose imagine that the test sample be balanced against the comparison standard. The zero current indicator will, however, only indicate a definite minimum at very high frequencies, even if resonance is established in the detector circuit by means of a condenser. Assume, further, that all the above precautions are employed and that the leads of the zero current detector are well protected against disturbances such as mentioned above. Yet the zero current detector will indicate a certain flux interlinked with the secondary circuit of the differential transformer. The cause of the disturbance can only be based upon capacity influences, which can be proved experimentally. For instance, when the observer touched different parts of the differential arrangement the telephone receiver (for this class of investigations, an oscillatory detector arrangement was employed as zero-current indicator) gave different sounds at the minimum. By putting the hand on one of the secondary terminals of the tranformer, the minimum was better. This phenomenon is due to charges and discharges causing a leakage current, flowing from the primary to the secondary turns of the differential transformer and such a stray current flowing from the turns of the telephone receiver thru the metal case and the hand of the observer to the ground. The primary coil, the secondary coil and the turns of the telephone receiver are regarded each as one pole of a condenser. This assumption can be made, as there will be not a strict mathematical treatment of this case; but this assumption is simply used for the proper interpretation of the cause of the above phenomena. Suppose, V_3, is the potential of the primary turns, V_2, that of the secondary coil, V_1, the potential of the turns of the telephone receiver, and the body of the observer has the potential V_o. Assuming further that C_{32} is the capacity of the condenser formed by the primary and secondary coil of the differential transformer, and C_{10} the capacity of the condenser formed by the turns of the telephone receiver and the body of the observer. Then, from the primary to the secondary turns of the transformer a charging current, $[V_3-V_2]\,\omega C_{32}$, flows, of which a certain part, $[V_1-V_o]\,\omega C_{10}$, flows thru the hand to ground. Suppose we touch one of the secondary terminals of the transformer, that is, that the same is brought to the potential V_o. Consequently the second stray current disappears and the first one becomes, $(V_3-V_o)\omega C_{32}$. It might be believed, that the increase, $\{[V_3-V_o]-[V_3-V_2]\}\,\omega C_{32}$ would affect the telephone receiver more and would not dim-

Digitized by Google

inish the sound. But if we bear in mind, that the body and therefore the potential V_o) is connected with one of the secondary terminals of the transformer, it is understood that practically most of the stray current will be led thru the observer to the ground. It would be a wrong expedient against these disturbances to ground one of the secondary terminals, as that would only diminish the sensitiveness of the arrangement. Instead the writer used a tube of glass for handling the slide resistance and a cord for turning the coils of the standard variometer. By this means the current, $(V_1 - V_o)\omega C_{10}$ could be made exceedingly small. (It is to be noted that for very precise measurements the telephone receiver is to be replaced by a galvanometer.) The first capacity current flowing from the primary to the secondary turns affected the telephone receiver much more. In order to overcome this disturbance the writer put a copper cylinder around the secondary turns. The cylinder consisted of enamelled copper wire. Along a longitudinal line the insulation was removed and all turns of the cylinder connected to ground. On an opposite longitudinal line, the protecting cylinder was cut in order that the damping action of the transformer might not be increased too much.

SUMMARY: The method described gives a ready means for determining the magnetizing force, the corresponding flux density, and permeability at any wave length whatever. In taking a series of readings for different ampere-turns and at a definite wave length, we may obtain

(a) the magnetization curve,

(b) the permeability-ampere-turns curve.

Since the suggested arrangement applies to any practically available wave length we have a convenient means to compare the B_{max}-values for very long wave lengths with the corresponding values determined at higher frequencies, and thus obtain a clear insight into the skin action of an iron core.

In a similar way the permeability-wave length curve may be found for a definite number of ampere turns. The method simultaneously determines either the total losses of the test sample or the losses due to direct current resistance, skin effect of the conductor, hysteresis and eddy currents in the iron core separately, and there can be obtained the

(a) watts/unit volume-wave length curve for a certain number of ampere turns,

(b) watts/unit volume-flux density curve at a constant wave length, and

(c) watts/unit volume-thickness of laminations curve for a constant wave length and a constant number of ampere turns; which enables the investigator to ascertain all the conditions which are necessary for determining the desired properties of any radio frequency apparatus containing a ferro-magnetic medium.

Moreover, by means of equations (14) and (15) one is able to experimentally investigate the dependance of the magnetizing force and permeability on the frequency.

Digitized by Google

LIST OF SYMBOLS USED

α	Hysteresis exponent.
β	Eddy current exponent.
B_{max}	Maximum magnetic flux density, number of lines of magnetic induction per square centimeter.
$C_{10}, C_{32}, \Delta C_1, \Delta C_2,$	Capacities in farads.
d	Thickness of iron lamination in centimeters.
δ	Hysteretic angle of advance.
E	Effective induced E. M. F. of N turns of the test sample.
E_{av}	Average induced voltage of a single turn.
η	Hysteresis constant.
F	Form factor.
f	Frequency.
Φ_{max}	Maximum flux traversing the test coil.
Φ_t	Flux traversing the test coil at any time t.
ϕ	Displacement of phase between terminal voltage and current of the test sample.
H_{max}	Maximum resultant field intensity in gilberts per centimeter.
I	Current flowing to the differential system.
$I'' 2$	Effective current value of the component of the exciting current of the test sample containing the higher harmonics.
I_h	Effective value of hysteresis current.
I_m	Effective value of magnetizing component of exciting current.
$I'_W 2$	Effective value of the energy component of the equivalent sine wave of the exciting current.
$I'_{WL}/2$	Wattless component of the equivalent sine wave.
$i/2$	Instantaneous value of the exciting current.
$i'/2$	Instantaneous value of the equivalent sine wave.
$i''/2$	Instantaneous value of the component of the exciting current containing all higher harmonics.
$j=\sqrt{-1}$	The imaginary unit.
$K_1, K_2, k_1, k_2, k_3, k_4, k_5$	Constants.

Digitized by Google

$L_s, L_{sc}, L_x, L_{xc}, L_2, \Delta L_1, \Delta L_2, \Delta L_x$	Coefficients of self induction in henrys.
l	Length of magnetic path in centimeters.
λ	Wave length in meters.
μ	Magnetic permeability.
N	Number of turns of the test sample.
r	Series resistance in ohms.
r_x'	Direct current resistance of test sample.
r_x''	Alternating current resistance of test sample.
r_x	Resistance of test sample under any condition.
Δr_c	Increase of the resistance of the test sample caused by core loss.
Δr_f	Increase of the resistance at the frequency f caused by skin effect.
S	Cross sectional area of iron core in square centimeters.
T	Period of radio frequency current.
V, V_1, V_2, V_3	Terminal voltages.
v	Volume of iron core in cubic centimeters.
W_c	Total core loss in watts.
W_{c1}	Total core loss in watts at a frequency f_1.
W_{c2}	Total core loss in watts at a frequency f_2.
W_e	Core loss due to eddy currents.
W_h	Core loss due to hysteresis.
ω	Angular velocity of radio frequency current.
ξ	Eddy current constant.
z	Resistance operator of variometer-resistance combination.
z_x	Resistance operator of test sample when no iron is present.
z_x'	Resistance operator of test sample when iron is present.

Digitized by Google

VOLUME 5 APRIL, 1917 NUMBER 2

PROCEEDINGS

of

The Institute of Radio Engineers

(INCORPORATED)

TABLE OF CONTENTS

TECHNICAL PAPERS AND DISCUSSIONS

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

PUBLISHED EVERY TWO MONTHS BY
THE INSTITUTE OF RADIO ENGINEERS, INC
ONE HUNDRED AND ELEVEN BROADWAY
NEW YORK

THE TABLE OF CONTENTS FOLLOWS ON PAGE 71

Digitized by Google

GENERAL INFORMATION

The right to reprint limited portions or abstracts of the articles, discussions, or editorial notes in the Proceedings is granted on the express condition that specific reference shall be made to the source of such material. Diagrams and photographs in the Proceedings may not be reproduced without securing permission to do so from the Institute thru the Editor.

Those desiring to present original papers before the Institute of Radio Engineers are invited to submit their manuscript to the Editor.

Manuscripts and letters bearing on the Proceedings should be sent to Alfred N. Goldsmith, Editor of Publications, The College of the City of New York, New York.

Requests for additional copies of the Proceedings and communications dealing with Institute matters in general should be addressed to the Secretary, The Institute of Radio Engineers, 111 Broadway, New York.

The Proceedings of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings in New York, Washington, Boston or Seattle.

Payment of the annual dues by a member entitles him to one copy of each number of the Proceedings issued during the period of his membership. Members may purchase, when available, copies of the Proceedings issued prior to their election at 75 cents each.

Subscriptions to the Proceedings are received from non-members at the rate of $1.00 per copy or $6.00 per year. To foreign countries the rates are $1.10 per copy or $6.60 per year. A discount of 25 per cent. is allowed to libraries and booksellers. The English distributing agency is "The Electrician Printing and Publishing Company," Fleet Street, London, E. C.

Members presenting papers before the Institute are entitled to ten copies of the paper and of the discussion. Arrangements for the purchase of reprints of separate papers can be made thru the Editor.

It is understood that the statements and opinions given in the Proceedings are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

COPYRIGHT, 1916, BY

THE INSTITUTE OF RADIO ENGINEERS, INC.

ONE HUNDRED AND ELEVEN BROADWAY

NEW YORK, N. Y.

Digitized by Google

CONTENTS

Digitized by Google

OFFICERS AND BOARD OF DIRECTION, 1917

(Terms expire January 2, 1918; except as otherwise noted.)

PRESIDENT
MICHAEL I. PUPIN

VICE-PRESIDENT
JOHN L. HOGAN, JR.

TREASURER
LOUIS R. KRUMM

SECRETARY
DAVID SARNOFF

EDITOR OF PUBLICATIONS
ALFRED N. GOLDSMITH

MANAGERS

(Serving until January 7, 1920)
ERNST F. W. ALEXANDERSON
JOHN STONE STONE

(Serving until January 1, 1919)
EDWIN H. ARMSTRONG
GEORGE S. DAVIS

(Serving until January 2, 1918)
LOUIS W. AUSTIN
JOHN HAYS HAMMOND, JR.
LLOYD ESPENSCHIED
JOHN STONE STONE
ROY A. WEAGANT

ADVERTISING MANAGER
LOUIS G. PACENT

WASHINGTON SECTION

EXECUTIVE COMMITTEE

CHAIRMAN
LIEUT.-COLONEL GEORGE O. SQUIER
War Department,
Washington, D. C.

SECRETARY-TREASURER
GEORGE H. CLARK
Navy Department,
Washington, D. C.

CHARLES J. PANNILL
Radio, Va.

BOSTON SECTION

CHAIRMAN
A. E. KENNELLY,
Harvard University,
Cambridge, Mass.

SECRETARY-TREASURER
MELVILLE EASTHAM,
11 Windsor Street,
Cambridge, Mass.

SEATTLE SECTION

CHAIRMAN
ROBERT H. MARRIOTT,
715 Fourth Street,
Bremerton, Wash.

SECRETARY-TREASURER
PHILIP D. NAUGLE,
71 Columbia Street,
Seattle, Wash.

Digitized by Google

SAN FRANCISCO SECTION

CHAIRMAN	SECRETARY-TREASURER
W. W. HANSCOM, 848 Clayton Street, San Francisco, Cal.	V. FORD GREAVES, 526 Custom House, San Francisco, Cal.

H. G. AYLSWORTH
145 New Montgomery Street,
San Francisco, Cal.

PAST-PRESIDENTS

SOCIETY OF WIRELESS TELEGRAPH ENGINEERS

JOHN STONE, STONE, 1907–8 LEE DE FOREST, 1909–10
FRITZ LOWENSTEIN, 1911–12

THE WIRELESS INSTITUTE

ROBERT H. MARRIOTT, 1909–10–11–12

THE INSTITUTE OF RADIO ENGINEERS

ROBERT H. MARRIOTT, 1912 GREENLEAF W. PICKARD, 1913
LOUIS W. AUSTIN, 1914 JOHN STONE STONE, 1915
ARTHUR E. KENNELLY, 1916

The Membership of the Standing Committees of The Institute for 1917 will be announced in an early issue of THE PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS.

Digitized by Google

Digitized by Google

ON THE NATURE AND ELIMINATION OF STRAYS*

An Investigation Under the Auspices of the Dutch East Indian Department of Telegraphs

By

Cornelis J. De Groot, Sc.D., E.E., M.E.

(Engineer of the Department of Telegraphs, Dutch East Indies)

Part 1. Radio vs. Cable Communication in the Tropics

One of the most troublesome phenomena met with in connection with long distance radio communication, where the signals are usually faint and of variable intensity, is atmospheric disturbances or strays. These interfere seriously with radio communication during the summer in temperate climates. Their magnitude increases to an overwhelming extent in the tropics, especially during those seasons when the sun attains its maximum altitude.

In the tropics, and at such times of the year, it is a task of the utmost difficulty for a radio engineer to establish and maintain communication. Particularly unfavorable under these conditions is the comparison between the cost of upkeep and operating reliability for radio communication and submarine cable communication.

The difficult undertaking of establishing radio communication on a regular basis in a tropical climate was voluntarily accepted by the Department of Telegraphs of the Dutch East Indies. Tho it cannot yet be said that a completely successful solution has been obtained of the problem of substituting the proposed radio service for submarine cable communication the incidental investigations have been of much interest. Systematic researches have been carried on which have resulted in the accumulation of a great quantity of valuable material dealing with such radio phenomena as the propagation of electromagnetic waves and the origin, propagation, nature, and elimination of strays.

It is this last information concerning strays which will constitute the main subject of this paper.

* Received by the Editor, October 15, 1916. Presented before The Institute of Radio Engineers, New York, December 6, 1917.

Digitized by Google

It may be a matter of astonishment that so unfavorable a region as the tropics was chosen in attempting to substitute radio communication for submarine cables; particularly when one considers that under much more favorable conditions as to strays, and cost of up-keep, the problem has not yet been successfully solved. It must be admitted, however, that special circumstances dictated the choice of radio service, assuming the feasibility of such communication.

These circumstances are the following:

(a) The East Indian Archipelago consists of a great number of islands separated by straits and seas, of enormous depth, 12,000 feet (3,700 meters) being quite common. In this region, earthquakes and similar disturbances of the sea bottom are frequent, and the coast line rises steeply.

Such conditions are not favorable for submarine cable work. Repairs are very difficult and sometimes impossible at such great depths, and in every case a first class cable repair steamer, with extraordinarily heavy hoisting apparatus, would be necessary. Especially is this the case in the much deeper waters of the eastern part of the archipelago. The existing cable steamer does not meet the above requirements; and since the communication was most urgently required, and since the establishing of communication in the eastern part of the Indies would have involved the purchasing of a second and larger cable steamer, an extension of the cable system was regarded as undesirable. The great extent of the archipelago, this being nearly 3,000 miles (5,000 km.) in length, would have necessitated keeping two cable steamers, at least, in commission at all times. The great frequency of earthquakes and sea disturbances of similar character would have resulted in frequent, and possibly simultaneous, breakdowns of the cable service with the result that the widely separated parts of the archipelago might have been out of communication for very long periods of time.

(b) As an additional advantage, radio stations afford the possibility of maintaining communication with ships at sea. Tho the traffic is not sufficiently extensive to justify the erection of radio stations for this purpose exclusively, especially as violent storms and fogs at sea are unknown in this part of the world, it still remains an additional advantage of the radio chain as compared to submarine cables. It is clear that navigation is facilitated by free communication to ships.

The advantages of a radio chain as regards ship communica-

Digitized by Google

tion are obvious from a naval standpoint, and were most readily realized at the beginning of the present war. It would have been almost impossible for the small squadron of Dutch men-of-war to maintain neutrality as perfectly as it did, had all points now connected by radio been dependent entirely upon submarine cable service.

(c) Another reason for embarking in the enterprise of estabishing reliable radio service in this tropical region was the apparent slightness of the risk, at least at the inception of the undertaking. The well-known Telefunken Company of Berlin entered into a contract with the Dutch Government to erect the chain of stations at a very moderate price and with full guarantee of continuous correspondence at the stated speed of twenty-four words per minute during all twenty-four hours of the day and every day of the year. The only exception to this guarantee was during such times as strays would have reached an intensity which would have become a menace to the apparatus and operators or such times as those during which an ordinary overhead telegraph land line would have been equally crippled. It appeared, however, after some years of systematic tests, that the conditions guaranteed in the above contract could not possibly be fulfilled and that even under much less strict requirements, a radiated energy of some six to eight times as large as that actually furnished was necessary to maintain anything like trustworthy communication during unfavorable parts of the year. By trustworthy communication is meant service comparable to that obtained with normal hand sending on submarine cables.

The Telefunken Company is only partially to be blamed for the poor results obtained since, at the time of the original contract, no one had the slightest idea as to the difficulties which were encountered in the tropics. My opinion in this direction is confirmed by the equally poor results obtained by other radio contractors in India at about the same time.

As a matter of fact, during the three most favorable months of the year, which corresponds roughly or most nearly with European conditions, the communication was entirely in accordance with the agreement.

At the time the contract was drawn up, the cost of erection, maintenance, and repair of submarine cables, was well known by long years of experience. The cost of erecting radio stations of the proposed magnitude could also be approximated closely. In consequence, the comparison between radio communication

Digitized by Google

and the cables seemed a reasonably favorable one, and competition between them not impossible.

Altho the apparent risk was not great, it must be appreciated that this enterprise indicated much energy and a broad-minded attitude on the part of the Dutch Colonial Telegraph Service. In facing this pioneer work, the Service undertook the first systematic investigation in connection with radio in the tropics. Tho success was not reached in every direction, much valuable material was obtained on the basis of which completely successful radio communication could be based in the future. In addition, from a scientific point of view, fascinating phenomena were encountered; thus casting much light over the laws governing the propagation of electromagnetic waves as well as on the nature and elimination of strays.

All of these advantages more than compensated for the disappointment incidental to the insufficient communication between the stations as erected; and, as a matter of fact, the stations have more than paid for themselves by the strategic value they have been shown to possess during the present war.

On the other hand, the necessity of enlarging these stations so as to radiate six to eight times their present energy was entirely unfavorable to the financial comparison instituted between radio and submarine communication and in a direction prejudicial to the radio service. The original apparent equality of first cost was dependent upon a curious circumstance. Normally, the radio service would have been obviously much the less expensive but a strict clause in the original contract required the Government to erect the stations on expensive reservations at great distances from existing towns, with accompanying high rates of transportation for materials, the building of new roads, special accommodations and houses for the staff, and huge initial expense in connection with the purchase and destruction of trees and vegetation on the sites of the stations. It is therefore not astonishing that the original calculations comparing radio and cable communication, showed substantially equality, and that the choice between the two was solely one of convenience.

Personally, I am convinced that with more up-to-date radio apparatus and with freedom in choosing suitable sites, independently of the contractor's wishes, radio communication will always be preferable to submarine cable communication under certain definite conditions. Such conditions are the following:

Wherever the traffic is of such nature as to permit an inter-

Digitized by Google

ruption of communication at the most of two hours per day (in consequence of thunder storms and entirely excessive strays) the radio service will be preferable.

For distances of more than 600 miles (1,000 km.) the cost of radio communication may, even in the tropics, be easily made less than that of cable service. In addition, the reliability and speed, as expressed in terms of words handled per day, may be made superior to that of normal cable service. Furthermore, radio telegraphy has the advantage of communication with ships.

Investigations which were carried on showed that the requirements of the contractors as to station sites were not necessary, and that the stations might easily have been erected in much more convenient and inexpensive locations. Needless to say, this knowledge is of great future use.

Radio service has great military and political possibilities. It has the great advantage that repairs are always local in nature. Spare parts, or even duplicate sets, could be kept in every station and skilled engineers or operators provided. Under these conditions, communication could hardly be interfered with by any ordinary disturbances, being subject only to extremely severe earthquakes, which are indeed a source of interruption to any type of communication.

In this regard, particularly, radio service compares very favorably with the submarine cables for in the latter case the breakdowns may cause a cessation of communication for several weeks.

PART 2. OPERATING CONDITIONS IN THE TROPICS

Tho the results of the comparison between the two competing systems of communication are interesting, the systematic research work concerning the propagation of the radiated energy and the nature of strays are more absorbing to the scientific worker.

Of this research work, only that portion directly concerned with strays will be summarized in this paper.

As an introduction to the conditions under which observations were carried out, a short description of the stations and their geographical location as well as some photographs thereof, are given. In Figure 1 is shown a map of the East Indian Archipelago on which are indicated clearly the stations under consideration. These are:

Landangan, 7° 40′ south, 114° east, and situated in the eastern part of the main island. From this island as a center,

Digitized by Google

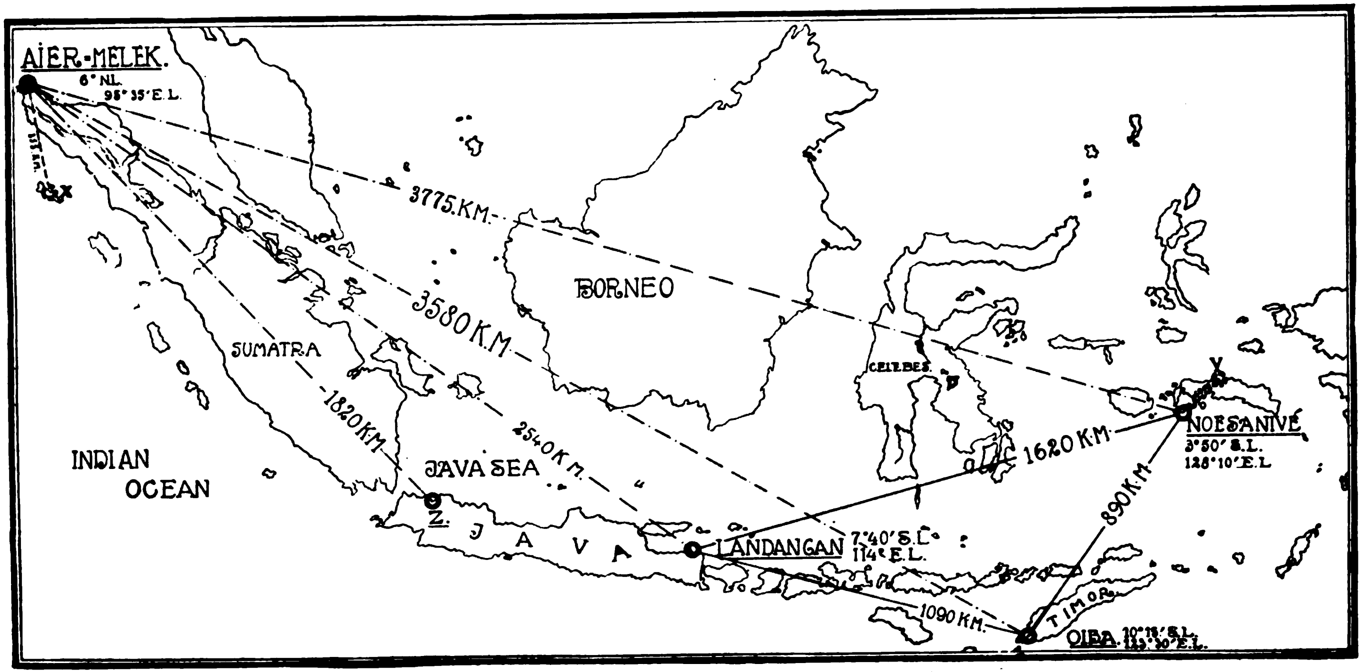


FIGURE 1—Location of Stations in Dutch East Indies

Digitized by Google

India is governed and the two other stations are merely secondary governmental centers, so that the main object of this communication is in governmental service.

Oiba, 10° 15′ south, 123° 30′ east, and near Timor, one of the secondary centers of government.

Noesanivé, 3° 50′ south, 128° 10′ east, and situated on the island of Ambon, also a secondary center of government.

The contractor had agreed to furnish continuous communication between Landangan and Oiba, 680 miles (1,090 km.), and from Oiba to Noesanivé, 555 miles (890 km.). The tests, however, were extended so as to include the unguaranteed direct communication between Landangan and Noesanivé, 1,010 miles (or 1,620 km.).

All three stations were of the same design and output and differed only slightly to conform to local conditions.

As the design is the well-known commercial Telefunken musical, quenched spark set, no detailed description will be given here. It is sufficient to note that all the stations were of the so-called 5 T.K. standard type, (this being 5 K.W. in the antenna). The prime mover was a 28 H.P. Deutz gasoline engine, starting on compressed air, and with belt drive to a 10 K.W., 500 cycle generator and exciter. The generator fed the closed core 220-to-12,500 volt transformer, which charged a group of Leyden jars. These discharged approximately 1,000 times per second thru an air-cooled, Wien, silver surface, spark gap, composed of 14 gaps connected in series. Since the generator system is worked near resonance, a high pitched note is produced in the receiving set.

The antenna and closed circuits were coupled closely and directly, and any one of four pre-determined waves could be readily radiated. These were a 600 meter wave for ship-to-shore work, and 1,200, 1,600, and 2,300 meter waves for long distance work. The 1,600 meter wave turned out to be the most desirable for direct communication between the three main stations, especially during the day time. At night, the 600 meter wave, which was not desirable during the day, was approximately as good as the 1,600 meter wave. At night, the 1,200 meter wave was slightly better than either the 600 or 1,600 meter waves. From the point of view of simplicity, the 1,600 meter wave was practically always used, with the exception of special tests intended to determine the relation between the working conditions when using different wave lengths. These latter tests showed, however, that the 1,200

Digitized by Google

meter wave length which was most efficiently radiated, was superior during the night time, whereas in the day, the combined effect of the better radiation at short waves and the better propagation of the longer waves, resulted in a most efficient wave length which changed with distance as well as with the hour of the day. On the average, this optimum wave length was about 1,600 meters for the 890 kilometer (530 mile) distance of transmission, and from 1,800 to 1,900 meters for the 1,090 kilometer (650 mile) connection.

The contractor, who was authorized to pick out the wave length at which the tests were to take place, decided after preliminary tests with wave lengths up to 3,500 meters, that the 1,600 meter wave should be the working wave thruout the day and night.

The 600 meter wave was radiated by a fan shaped, six-wire antenna in connection with an earth of radially spreading galvanized iron wires. The longer waves were radiated from a four wire umbrella, or rather ("X") shaped, antenna in connection with a counterpoise ground made of twelve wires of copper-plated steel.

These arrangements proved best for all three stations so far as maximum effective radiation at the different wave lengths was concerned.

Both antennas and the counterpoise (which was elevated to the average height of 60 meters (20 feet)), were supported by a center, steel lattice tower, 85 meters (280 feet) in height. This tower is of the well-known triangular cross section type, much used by the Telefunken Company, and stands on a ball-and-socket joint, being stayed by two guy sets each of three solid rod stays, each stay terminating in a concrete anchor block. These stays were made up of sections of rods three meters (10 feet) long and three centimeters (1.2 inches) in diameter. The approximate stress on each stay was 19 tons (17,000 kg.). In this way, the towers were held in vertical position tho the support was flexible.

In two of the three stations, both stays and towers were insulated from each other and from the earth by glass plate insulators, but at the Noesanivé station, frequent earthquakes made it necessary to avoid this construction and the tower and stays were all directly connected to each other.

Measurements based on my method[1] of measuring radiation resistance and dissipative resistance showed clearly that this

[1]"Jahrbuch der drahtlosen Telegraphie, etc.," volume 8, part 2, pages 109-121.

Digitized by Google

earthed tower construction produced a slight diminution in the radiation resistance as well as a small increase in the dissipative resistance. There resulted a slight decrease of the total antenna resistance as well as of the efficiency of the antenna as a radiator. The effects described were measured only for the 1,600 meter wave.

The practical result was that the Noesanivé station proved slightly inferior for transmission and slightly superior for reception as compared with the two other stations. The relative superiority and inferiority were, however, quite slight, and in no way comparable to the advantages resulting from greater security against earthquakes. An additional feature of the construction of the Noesanivé tower was that it was anchored to its base in such a manner as permitted play in the ball-and-socket base joint but prevented the tower from jumping out of its support in the case of serious earthquakes. As an additional precaution against snapping of the main stays, each stay was paralleled by a second auxiliary stay connected between the same end points. The auxiliary stays were made so as to have more sag than the main stays and consequently would come into operation only after the main stay had broken. These auxiliary stays are shown in Figure 3.

The area of all the stations was 220 meters (720 feet) by 440 meters (1,440 feet), the tower being at the center of the rectangular area. Four additional masts only 16 meters (52 feet) high were provided at the corners to permit the four antenna wires to be held. These four small masts also supported eight of the counterpoise wires. Four seven-meter (23 foot) poles supported the remaining four counterpoise wires. The fundamental wave length of the large antenna is about 1,100 meters and the capacity at 1,600 meters wave length was about 0.00266 microfarad. The corresponding figures for the smaller antennas were 450 meters wave length, and 0.00156 microfarad capacity. There was measured in the antenna an output of about 4 K.W. for the 600 meter wave and 5 to 7 K.W. for the longer waves.

Transmission is accomplished in the usual way by a hand key which operates a quick-acting magnetic relay key in the transformer low tension circuit.

Earth arresters are provided as well as an appropriate form of switch for changing from sending to receiving.

For reception, the normal Telefunken, crystal detector receiving set was provided, consisting of an antenna tuning circuit and aperiodic secondary system coupled magnetically

Digitized by Google

and closely thereto. The secondary system contained the crystal rectifier and the telephone. The coupling employed in practice gave the loudest telephone response; that is, the coupling was the so-called most "economical" one, whereby one-half of the antenna energy is converted into useful energy in the detector. The maximum possible energy conversion is thus achieved.

While this method gives the greatest signal strength, and therefore the longest transmission range, it is of doubtful value when considering the elimination of interfering signals or strays the antenna damping being doubled as compared to that of the unloaded antenna. The selectivity is therefore diminished, and the detector circuit is too closely coupled to the antenna circuit and takes up or responds to the transferred and forced vibrations, such as strays in the antenna. During the greater part of the year, however, communicating signals were so weak that no usual method of reception was possible with the apparatus as installed. A loosely coupled intermediate circuit was available, and was sometimes used at night to diminish the intensity of strays; since, in this case, signals were sufficiently loud to permit the weakening which always occurred with this arrangement.

Whereas *transmission* with the large antenna and *counterpoise ground* were found best for all four wave lengths; in *reception* the best results were obtained using a *conductive* ground, the relative advantage in reception being as much as 50 per cent. as compared with the counterpoise ground.

The detectors were silicon crystals and no special means were provided to avoid the enormous strays existing in these parts of the world.

A group of illustrations give a clear idea as to the nature of the stations. In Figure 2 is shown the exterior of the Landangan (or Siteobondo) station. The tower was 280 feet (85 meters) high. In Figure 3 are shown the station buildings. Starting at the left, there are visible the machinery room, repair shop, a long gallery which prevented the noise of the machinery room from interfering with the receiving operators, the operating room, the inspector's quarters, and an auxiliary building. In Figure 4, the base of the 60 meter (200 foot) tower at Landangan is shown. The ball-and-socket base construction, triangular cross section of the tower, insulators, internal ladder, and radiating ground wires are all clearly visible. The machinery room at Landangan is shown in Figure 5, the belting from the gasoline

Digitized by Google

engine in the rear and the generator in the front, being depicted as well. In Figure 6 is illustrated, in greater detail, the generator at Landangan.

The operating room at Landangan is shown in Figure 7.

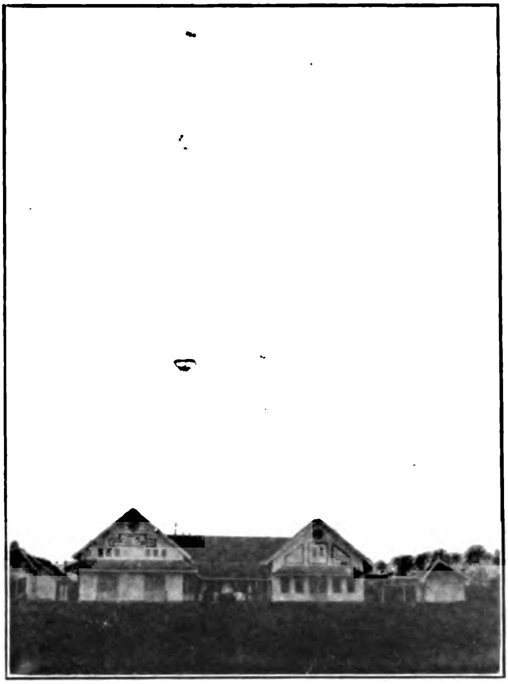


FIGURE 2—Landangan (near Siteobondo), 85 m. (280 foot) Tower, Insulated

At the left is seen the operating table with its usual Telefunken receiver, while to the right are shown the high tension panels and frames of the transmitter. The middle panel supports the antenna and coupling inductances and the shortening condensers, while the right hand panel supports the spark gap, primary circuit inductance, and primary capacity. Back of this panel is seen the high tension audio frequency transformer, and between the panels is visible the antenna ammeter. The transmitter at Noesanivé is shown in greater detail in Figure 8, wherein the means of changing wave length readily by the insertion of moveable plugs is clear. The system of ventilating the spark gap by a blower, placed beneath, as well as other details are shown.

Digitized by Google

In addition to the tests carried on between the three stations already mentioned, some tests were made in connection with the following:

(a) The station at Aer-Melek, 6° north and 95° 35′ east, working as a shore station on a 600 meter wave. This station is of the same design but only half the power of the three former stations.

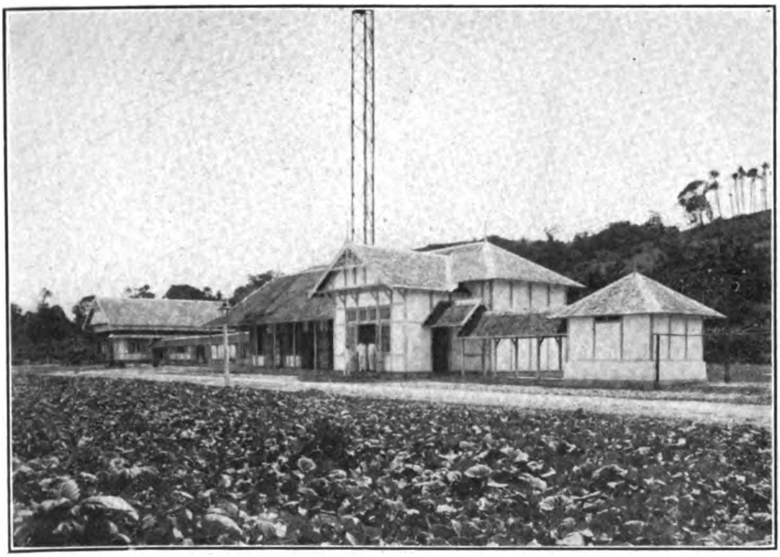


FIGURE 3—Station Buildings
Starting at left—Machinery Room, Shop, Gallery (40 m., or 130 feet) Long, Operating Room, Inspector's Quarters, Gallery, Conveniences

(b) Men-of-war at the points marked *X* and *Y* on Figure 1. The output of these stations was about equal to that mentioned under (a).

(c) A small old-fashioned station at Batavia (*Z* on Figure 1).

Following this general description of the chain of stations, we shall consider one of the subjects technically investigated; namely,

Part 3. Classification and Elimination of Strays

As is generally known in radio practice, these atmospheric disturbances produce in the operator's telephones a hissing, crackling, and rattling noise, and are not due to other stations

Digitized by Google

or electric power plants in the neighborhood, but are propagated thru the ether and therefore received in the same way as the signals originating at other points.

The origin of strays, in many cases, is quite obvious but in other cases almost untraceable. Even before the invention of radio telegraphy, many types of strays were known, especially on long over-head telephone and telegraph lines in mountainous

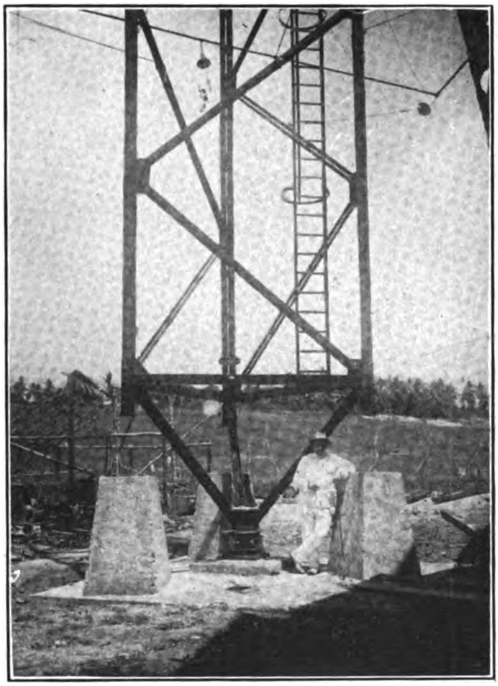


FIGURE 4—Base of 60 m. (200 foot) Tower at Sabang (Showing Ground Wires)

tropical regions, but the interference produced in these cases was by no means so great as in radio communication.

As a general rule, it may be stated that strays are at their worst during the night time and in the tropics, and that their intensity and character is a function of the time of day and of the season of the year.

The worst trouble from strays is experienced, generally speaking, during those months when the sun's altitude is greatest and consequently the poor periods of communication do not

Digitized by Google

occur simultaneously over the entire earth. During my own tests, it was found that in the tropics, the most unfavorable time was that of the west monsoon (or trade wind) which lags somewhat behind the time of greatest altitude of the sun.

A very unfavorable circumstance connected with radio communication in these parts of the world is that the periods of maximum strays coincide with those of marked fading and

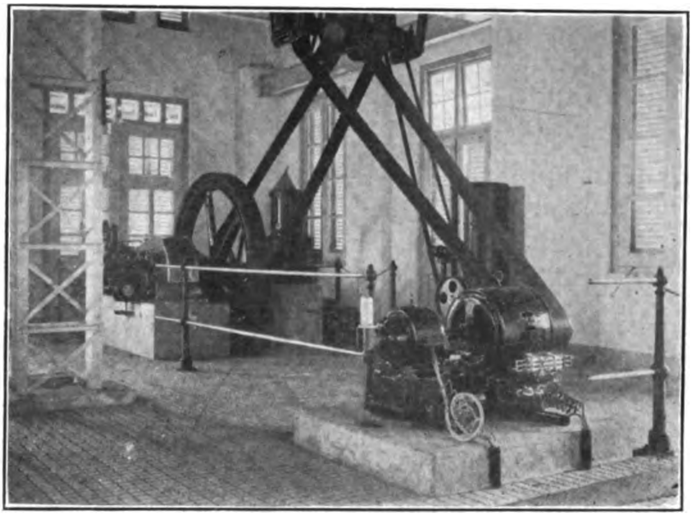


FIGURE 5—Machinery Room at Landangan (Siteobondo)

diminution of signal strength during the day time. At some of the receiving stations, this diminution brought the signals down to inaudibility.

The result of this unfortunate combination was that during the very worst months, signals were much too weak to drown out the strays of maximum loudness and on some occasions not a single word could be received during the day time.

A fortunate circumstance connected with these days of poor transmission was, however, that the night disturbances were not much worse than those during the afternoon, and on the other hand, for the wave lengths used, the night signals in these parts of the world increased to at least 1,000 times audibility, thereby becoming more than 30 times as strong as the best signals during the day time. It therefore became possible at

Digitized by Google

night to get the delayed messages thru, working at very slow speeds and repeating messages, sometimes, as many as six times. Thus, by extraordinary stress on the operators, no message was delayed for more than forty-eight hours.

The above statement of conditions shows most clearly how unfavorable a field for radio communication are the tropics; and that for the existing stations, at least, communication of the same order of reliability as that existing on submarine cables, could not be expected.

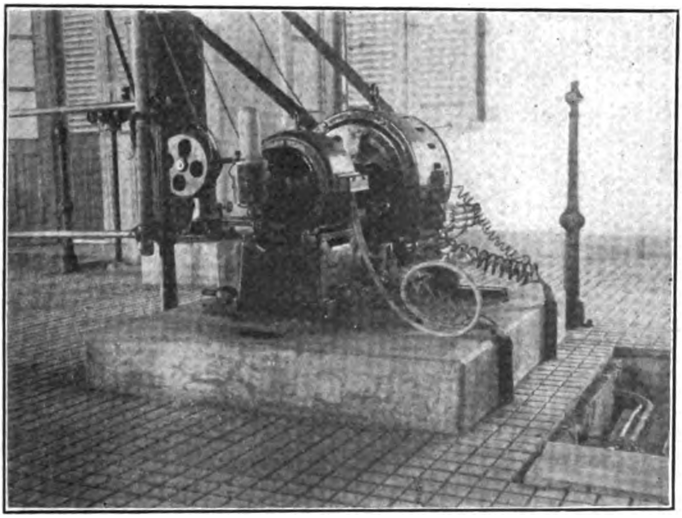


FIGURE 6—Generator at Landangan (Siteobondo)

It should be pointed out, however, that during the favorable seasons of the year, the stations worked satisfactorily and that the same reliability and speed as that obtained on submarine cables was then available.

For measurements made, during more than a year, of the variation in signal strength and from numerous estimates of the strength of the atmospheric disturbances, it was found that during the most unfavorable times approximately six to eight times as large an output was necessary, as compared with the favorable season, for suitable communication. It was further found that, even with this increased power, there were a couple of hours each day which would have to be abandoned for working

Digitized by Google

because of the impossibility of eliminating the very worst strays and thunder storms.

Since the fading of signals during the day time is a very unfavorable circumstance in the tropics, it is obvious that in these parts of the world especially, successful competition with submarine cables is dependent upon the development of means of overcoming strays. On the other hand, the invention of such

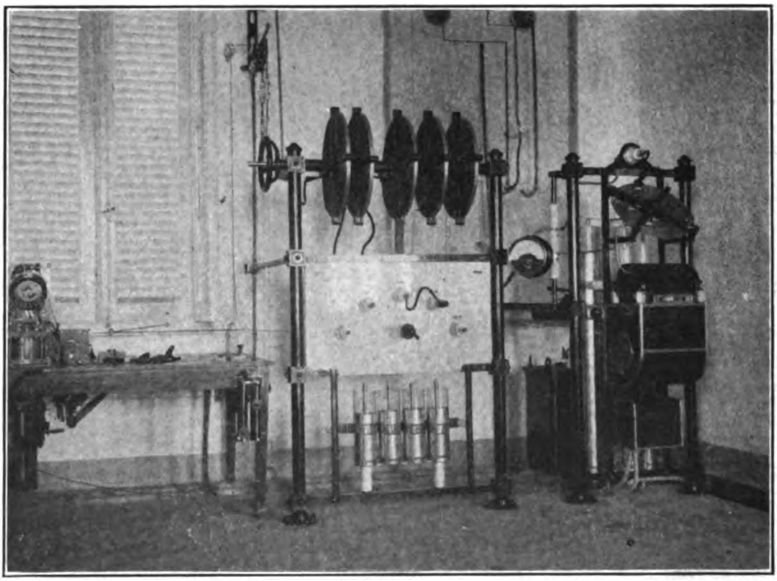


FIGURE 7—Operating Room at Landangan (Siteobondo)

means is possible only when a clear understanding exists of the mechanism of their production. The doubtful success of most of the inventions in this direction must be attributed to the ignorance of the inventors of the fact that several classes of atmospheric disturbances exist. Generally their inventions are aimed at only one of these classes. The results were unsatisfactory in all cases since the other types of strays remain harmful. Furthermore, most of the means employed to reduce strays do not even completely cut off the one type of strays against which they were supposed to be devised.

As a matter of fact, systematic observations were necessary,

Digitized by Google

and these observations were arranged to classify stray disturbances as follows:

(a) According to the trouble they gave and the interference which they caused with communication; (specifically as to loudness and frequency of recurrence).

(b) According to their apparent difference in quality or electrical characteristics, so as to enable a determination of their source.

(c) Detailed tests were then made to separate the different classes as indicated under heading (b).

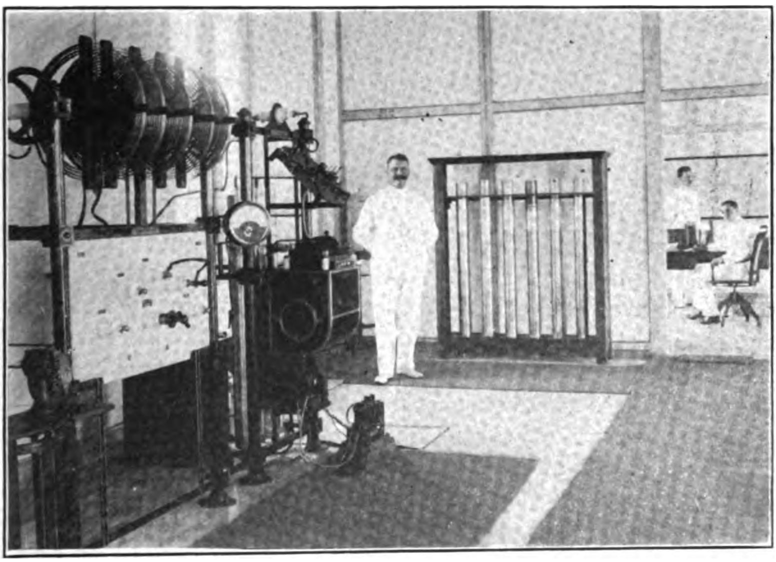


FIGURE 8—Transmitter at Noesanivé

A. Observations on the Loudness, and Frequency of Recurrence of Strays

The quantities in question were estimated by the operators, usually twice every hour, and in accordance with a scale of values stated below. At the same time the cloudiness of the neighborhood around the station, temperature, humidity, air pressure, wind direction, and strength of wind were stated, so as to give some indication of the dependence of atmospheric disturbances on all the factors stated above. It will be noted that the scale of value is a practical communication scale and is intended to

Digitized by Google

be of value in connection with actual working. The scale of values follows:

0. *No Disturbance* (This case *never* occurred).

1. *Weak Strays.* These were of such intensity as not to interfere to any extent with musical spark signals (1,000 sparks per second), corresponding to a loudness of 100 ohms shunted across a telephone of 1000 ohms resistance. Such an audibility is generally referred to as "ten times audibility." *This loudness of signal is referred to hereafter as the standard signal.*

2. *Medium Strays.* These, tho troublesome to some extent when the standard signal was being received, and forcing the operator to have occasional words repeated, still permitted communication.

3. *Strong Strays.* While these strays permitted the carrying on of communication with much trouble, at slow speeds, and with frequent repetition (while working with the standard signal), they did not entirely stop communication.

4. *Heavy (or very heavy) Strays.* These made communication quite impossible with the standard signal but permitted working with very strong signals (between 500 and 1,000 times audibility).

5. *Overwhelming Strays and Thunder Storms.* These naturally made communication quite impossible even with the strongest signals which could be produced in practice. This case was almost never experienced, except during one or two hours of the very worst days during the most unfavorable part of the year.

After very many observations, it can be stated that the following signal strengths are desired when 1,000 sparks per second are employed at the transmitter and an ordinary speed of transmission of twelve words per minute.

Class 1: Signals of 10 times audibility (100 ohms shunt in parallel with 1,000 ohms telephone).

Class 2: Signals of 20 to 30 times audibility.

Class 3: Signals of 60 times audibility.

Class 4: Signals of 250 to 500 times audibility.

Since class 4 is often required during the bad season and since class 1 is the class which is encountered during the good season, it is quite apparent that during the unfavorable season the radiated energy of the station must be at least six to eight times as large as during the favorable season, especially since the absorption and variation in strength of the signals is more marked during these unfavorable parts of the year.

In addition to the classification of strays which is given, in strength from 0 to 5, these atmospherics were registered, from

Digitized by Google

time to time (when they were very loud), on a tape by means of an ordinary Kelvin syphon recorder of the submarine cable type.

A record of this kind is shown in Figure 9 which gives an

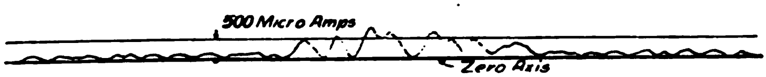


FIGURE 9—Tape Record of Medium and Strong Strays Taken with Syphon Recorder

excellent picture of strays of classes 2 and 3. These types of strays are present every afternoon in the tropics on an average and extend over the whole year. Their limits of strength are between 1 and 4.

The coil of the syphon recorder was of some 200 ohms resistance and was connected to that point in the receiving apparatus where the telephone receivers were normally placed. Since the impedance of the syphon recorder coil was not very suitable in view of the much higher resistance of the silicon detector employed, and since the receiving apparatus was not very sensitive, very strong impulses only could be recorded in this way. This may be easily seen when it is stated that the straight line at a distance of about 2 millimeters from the zero line of the recorder was made by the syphon with a continuous uni-directional current of 500 microamperes was passing thru the instrument, corresponding to an e.m.f. of 0.1 volt at the terminals. It is quite clear on observing the tape that on the average afternoon of the year, atmospheric disturbances will cause the detector to generate e.m.f.'s of several volts.

Strays of the worst class handled (that is, ranging between classes 4 and 4.5), forced the syphon to run off the tape and must have produced rectified detector currents of the order of some 3,000 microamperes.

If it be recalled that the standard signal of ten times audibility produced only 0.15 microamperes in the recorder coil, and that a signal of 500 times audibility (which could be received thru almost all strays) produced only 7 microamperes; it is a matter of extreme astonishment that signals can be read thru strays as readily as is the case. The superiority of the musical signal is obvious since it is picked up thru noises giving direct currents in the coils of the recorder or telephone receiver as much as 400 or 500 times the current corresponding to the signal itself.

As a matter of fact, these very strong atmospheric dis-

Digitized by Google

turbances will result in a loss of some words. It is clear, however, that a signal which pierces all strays and is 500 times audibility, gives a deflection on the tape of only 0.02 mm. (0.008 inch) and therefore is not detectable. On the other hand, the continuous crackling atmospherics of small amplitude in Figure 9, which would not cause the loss of any signals, still represented strays 20 times and more as strong as signals of 500 times audibility. This again brings out clearly the superiority of musical signals.

The tape, on the other hand, records the average atmospheric disturbance during the afternoon in the tropics, and shows clearly how difficult radio communication is under these circumstances. We may take as the basis of comparison, that a signal of 500 times audibility gives an unreadable deflection of 0.02 mm. (0.008 inch) while the actual strays give deflections of the order of millimeters.

B. Classification of Strays as to Electrical Nature and Source

The *strength* and *frequency* of *recurrence* of strays were the most important factors from the point of view of the designer, since they determined the necessary signal strength at the receiver and therefore the output of the transmitting station. Of course, the variation of received signal strength and the speed of transmission must be considered.

The *source* of strays and the mode of their propagation is of the most *scientific* value, altho such knowledge also assists the designer in devising improvements for rendering strays harmless and therefore permitting the maintenance of service with smaller station outputs. In order to procure this necessary knowledge, the operators were ordered to note the typical features of disturbances which were received, in order that a possible classification thereof, relative to origin, might be considered. In this way we succeeded in getting three distinct types of atmospherics.

Type 1: *Loud and sudden clicks* occurring in more or less widely separated groups. When these are not mixed with other disturbances, they do not interfere seriously with communication. They cause the heavy dominating groups of Figure 9. Generally, they will result in a loss of a single word in a message for each of the widely separated groups, and they were shown to *originate in nearby or distant lightning discharges.*

Digitized by Google

Type 2: *A constant hissing noise* in the telephone receivers giving the impression of a softly-falling rain or of the noise of water running thru tubes. This type occurs only occasionally when there are dark, low-lying electrically charged clouds near the receiving antenna.

This type was studied in great detail by one of my collaborators, Lieutenant H. G. Holtzappel of the Royal Dutch Navy, and now Engineer of the Dutch Indian Telegraph Service. These strays proved to be intermittent, unidirectional currents in the antenna. A direct current galvanometer switched into the antenna without any rectifier showed a deflection corresponding to these strays.

The hissing noise in the telephones as well as the fact that the condenser in series with the galvanometer altered but did not stop the deflection, proved, however, that we had to deal here not with ordinary direct current but with uni-directional impulses. The ordinary course of events with this type of strays was the following: The galvanometer gave an increasing deflection for about one-quarter hour, and a maximum of some 0.3 milliampere effective current was reached. Thereafter, the deflection decreased for another quarter hour and strays became normal again.

At the same time, incoming signals had the opposite tendency to become weaker and weaker, and after one-quarter hour they began to increase until the normal signal strength was again obtained at the close of the disturbance.

Lieutenant Holtzappel attributed the fading away of the signals to the alteration of the antenna constants by the passing clouds. We should rather suggest (or possibly add thereto) the alteration of signal strength caused by overload of the detector and consequent diminution of sensitiveness of the detector. The antenna current produced by these strays is rather strong, as has been stated, and the hissing sound produced in the telephones shows that a large amount of energy is being transferred to the detector.

As disturbances of the type are rather rare and last for only a short period, they did not interfere seriously with communication and are rather of *scientific* than of engineering interest.

I would suggest that these disturbances are due to physical contact of the antenna with charged particles or to an invisible brush discharge of the antenna toward the low-lying, highly charged clouds. The fact that the current induced in the antenna grows and diminishes synchronously with the arrival

Digitized by Google

and departure of the clouds hints at the correctness of the latter solution.

Type 3: This type produces a *continuous rattling noise* in the telephone something like the tumbling down of a brick wall. Such strays are *always present.* Their strength is a function of the period of the year and they are most troublesome in the afternoon and night. They are not well known during the day time in temperate climates, as in Europe, but are always present in the tropics.

Since these disturbances are of a continuous character, they are the most troublesome to handle; and, in fact, frequently suppress communication entirely. Often during the period of the west trade wind or monsoon, they are accompanied by heavy thunder storms, these latter causing disturbances of type 1, tho this is not the general rule for all seasons of the year. As a matter of fact, the maxima of types 1 and 3 do not coincide at the same portions of the year.

Both types 1 and 3 do not affect to any noticeable extent the loudness of the signal, as do strays of type 2. The signals are merely actually overwhelmed by the superior loudness of the strays.

So far as these disturbances were known in Europe, they were largely attributed to distant tropical thunder storms.[2] Dr. Eccles' well known theory is based on this assumption. It will be proven further on that Dr. Eccles' theory does not cover strays of type 3 since these have been shown to be aperiodic. In contrast, strays of type 1 have been shown to have only a very limited range, especially during the day time.

On the other hand, M. Dieckmann[3] has already pointed out that other disturbances may possibly be produced by sudden alterations of the potential distribution in air levels near the earth. It was therefore thought of interest to investigate to what extent the three types of strays were different in nature and source, in order that they might be separated electrically.

C. Tests for the Separation of Different Types of Strays

The means of investigation in this direction were given by Dieckmann himself in that he recommended the use of an aperiodic shielding cage around the antenna. If this cage is

[2] Dr. Eccles' paper, September 4 and 11, 1912, before the "British Association," and "Jahrbuch der drahtlosen Telegraphie, etc.," volume 7, part 2, page 203.

[3] M. Dieckmann, "Luftfahrt und Wissenschaft," part 1, 1912.

Digitized by Google

suitably designed it will permit signals and such periodic disturbances as those of type 1 to pass thru, and reach the antenna; and they will be received almost unweakened. On the other hand, aperiodic variations in the static field around the earth and other aperiodic disturbances would not reach the detector, the antenna being screened from the earth field by the Dieckmann cage.

As such a cage is not easily built around extensive antennas, a special antenna was built for this purpose, consisting of phosphor bronze wire of 1.5 mm. (0.06 inch) diameter, surrounded by a vertical cage. The length of both the wire and this cage was 30 meters (100 feet).

The cage consisted of four vertical hemp ropes placed parallel to the antenna wire and at equal distances from it. The four ropes were linked together every 50 centimeters (20 inches) by horizontal square loops of galvanized iron wire, making a large cage, the section of which measured 50 centimeters by 50 centimeters (20 by 20 inches).

As these squares of wire were all placed perpendicular to the antenna wire, they could not interfere seriously with the reception; but could only increase the effective antenna capacity.

All sixty of these squares were connected aperiodically to each other and to the earth by a thin high resistance manganin wire. Afterward it proved possible to connect them by a copper wire and to connect the entire system to the earth from this wire thru the high resistance without spoiling the results. The best solution remains, however, to have resistance coils inserted in the down leads, so that practically no part of the cage can swing electrically.

Since the antenna under test was supported by a mast from which other antennas were also suspended, these antennas and all other parts of the masts and stays that could be set into electrical vibration had to be grounded thru high resistances.

This precaution is very necessary to make the cage function effectively; since otherwise aperiodic strays would cause the above systems to vibrate by shock excitation in their fundamental frequencies and the electromagnetic waves produced by them would pass thru the cage and reach the test antenna. In this way, strays would be propagated thru the cage and received.

Other investigators have not found the Dieckmann cage of any use and I can attribute their failure only to lack of the proceeding precautions.

Digitized by Google

After the precautions mentioned were carried into practice, however, we found Dieckmann's statements as to the usefulness of the electrostatic shielding cage to be strictly confirmed, inasmuch as a certain aperiodic type of strays was quite suppressed thereby. The result of comparative tests was that on afternoons when distant lightning showed in the sky, loud clicks produced by atmospherics of type 1 were received regardless of whether the cage and surrounding oscillators were aperiodically earthed or not.

While observing these distant lightning flashes, almost every click or group of clicks in the receiver coincided with a distant flash, thus proving that the lightning type of atmospherics (Eccles' type) cannot be cut off by the Dieckmann cage and for this reason must be of periodic character as heretofore supposed.

It should be noted that the strength of signals received when using the Dieckmann cage was not appreciably reduced.

On the other hand, at night time, after thunder storms and rain in the afternoon (the neighborhood being then quite free from lightning disturbances), rattling strays that could still be heard as long as the cage and neighbouring oscillators were insulated, would be completely cut off as soon as all these conductors were aperiodically grounded.

This proved that this particular type of strays (of type 3) was not of periodic character but must have been of the aperiodic type found by Dieckmann.

The type 2 disturbances did not happen to occur during these comparative tests, but since their natural source is known, as before stated, it is easily seen that the Dieckmann cage must eliminate them.

The only type not cut off by the cage seems to be type 1, or the lightning type of strays.

We shall next prove that these strays of type 1 are by no means the general type they were supposed to be by Dr. Eccles. Thereafter, it will be clear that strays of type 3 are the most *important* and *main type* of strays.

Digitized by Google

Proof that the Lightning Type of Strays is Not the Most General Type (as supposed by Dr. Eccles)

and

That the Difference Between Day and Night Strays is Not Due to Differences of Absorption Between the Lightning Center and the Receiving Station

(a) The continuously present strays of rattling character, without much space between the different groups, faint in the morning, stronger in the afternoon and at least equally strong or even stronger at night, do not originate in distant lightning at all. This is clearly shown by the above-mentioned tests with the Dieckmann cage. These strays were easily screened off, whereas strays originating in lightning passed thru.

(b) The Eccles' theory presupposes a long range for strays originating in lightning, and especially during the night time because of the lack of absorption in the intervening medium. This supposition must be doubted. At our three stations, we frequently had to ground one of the receiving antennas because of dangerous and violent thunder storms in its immediate neighborhood. On the other hand, at the same time both of our other stations were continuing their communication without noticing any trace of extraordinary strays.

As the stations are only between 890 and 1610 kilometers (550 and 940 miles) apart, and thunder storms at one station did not produce noticeable disturbances at our other stations, there is no way of understanding how strays originating in thunder storms could reach temperate zone countries, (e.g., in Europe) at least ten times as far away and produce serious disturbances there. As a second proof of the short range of disturbances produced by thunder storms, it will be remembered that on nights following afternoons during which a thunder storm occurred with heavy rain fall, no strays originating in thunder storms were received. This was known by the fact that during such nights, the strays could be cut off by the Dieckmann cage.

Since the strays produced by the above-mentioned thunder storms were clearly local in character, it was obvious that distant thunder storms do not produce appreciable disturbances.

(c) Dr. Eccles takes the tropics as the origin of thunder storms. This being supposed to be their origin, there could be no large difference between strays during the day and during the night, the source being at all times comparatively near at hand.

123222B
Digitized by Google

Tho this point of view is partially supported by the fact that there are some times of the year when strays are almost as loud in the afternoon as during the night, still there is always enough difference, even in the worst months (and especially in those months during which strays in the day time are not strong), to make it certain that the tropics are not the center of strays originating in thunder storms.

The tropical regions cannot be a center of lightning storms and resulting strays for the reasons mentioned; and, in addition, they can not be at a great distance from a long range center, since, in the latter case, strays at our different stations, tho of different loudness, should always occur at the same moment. This is positively shown not to be the case by experiments; tho the same average daily and annual laws of intensity variation are found. The same definite noise or burst of strays is not heard at the same moment by the different stations.

As our stations are not in the supposed center of stray origin and since they are also obviously not outside of this center, the stray center of Eccles can not exist. There are, of course, centers of wave propagation in the neighbourhood of thunder storms but the range of these strays is certainly less than 900 km. (550 miles).

Consequently the stray phenomena observed in Europe can not simply be explained on the basis of the assumption of a tropical thunder storm center and subsequent variations in the strength of strays caused by changes in propagation thru the intervening ether. It is clear, then, that the most generally present type of strays, namely, those of type 3, must be generated in some other way than that suggested by Eccles, that is, by tropical thunder storms. And the simultaneous existence of the different types of strays may account for the failure of the many arrangements attempted to eliminate strays.

Marconi's original "X-stopper," which operated on the assumption of a definite frequency of the incoming strays, could only reduce strays of type 1, but was not effective in practice because it failed to eliminate strays of types 2 and 3.

The Dieckmann cage could only eliminate strays of type 2 and 3 but could not prevent strays of the first type from reaching the detector.

Since the investigators were not aware of the different existing types of strays, both of the devices were rejected as being non-operative.

Every means, such as loose coupling in the receiver and

Digitized by Google

simultaneous detuning of the intermediate circuit and also Marconi's balanced detectors (which helped for all types of strays to a certain degree) was based only on the principle of weakening of strays to a greater extent than the signals, and therefore could attain only partial success. The Marconi balanced crystal receiver is shown in Figure 10. Later in this

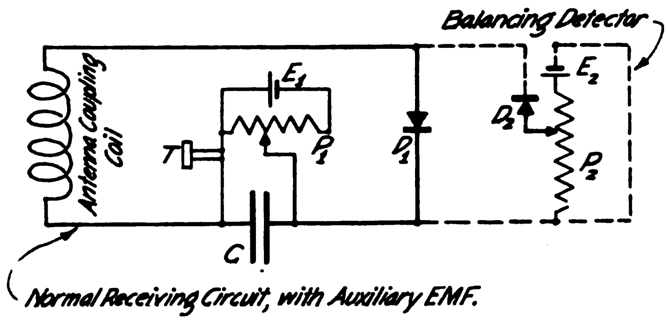


FIGURE 10—Marconi Balanced Crystal Receiver

paper, I shall describe a device of my own employing only a single detector but giving similar results to those which Marconi obtained, but with two detectors. I shall describe also several other devices, the principal one of which might be expected to be completely successful.

As to the existing devices, *with the exception of the last-mentioned one*, none proved as effective as the musical character of the transmitting note; which, as stated, enabled the high selectivity of the ear to pick out signals thru strays of from 100 to 500 times as great intensity.

Before proceeding to the last portion of this paper, an explanation of my own as to the origin and propagation of the dominant type of strays (those of type 3) which are not covered by Dr. Eccles' theory, will be given. I shall first describe several arrangements which I devised to eliminate strays and interferences from other stations.

(a) The first device is similar in action to Marconi's balancing detector, but needs only one detector. It is effective against very heavy strays, but especially against interfering stations. The arrangement consists in applying to a carborundum-steel detector, an additional constant e.m.f. in the reverse direction from that generally used. The diagram of connections is shown in Figure 11, and will be seen to be the same as that of

Digitized by Google

the Marconi balancing scheme with the exception of the omission of the second crystal. The e.m.f. E_1 is reversed so that the direct current flows in that direction for which the crystal shows the smallest conductivity. As is generally known, this weakens the reception to something like 50 per cent. of the available rectified current as against the optimum rectification obtained by applying the e.m.f. in the right direction. Still, reception is many times stronger than when using the detector without any additional applied e.m.f.

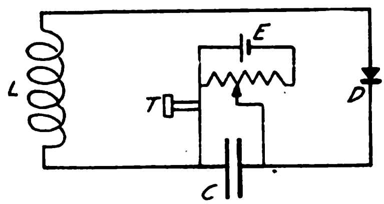


FIGURE 11—Stray Reducing Circuit Operating with Reversed Auxiliary E.M.F.

On the other hand, the reverse applied steady e.m.f. changes the characteristics of the detector as Figure 12 shows. The result is that weak signals are received much more loudly in proportion and absolutely than stronger ones; and that for a certain strength of signal and the corresponding applied e.m.f., there is no rectified current at all and therefore no reception.

I was easily able to make the loud signals from a steamer in the neighborhood of one of our stations inaudible by applying a suitable e.m.f. in the reverse direction. At the same time, signals 100 times weaker were being received from a distant station. As regards strays, the device operates in the same way as the balancing detector scheme; that is, there is only one strength of strays which can be made completely inaudible. Stronger strays are weakened and signals are similarly weakened, suppression depending upon their intensity. The device is therefore much more useful for the elimination of powerful interference from stations of constant loudness; and particularly so since these can be cut out with increasing ease, the louder they are. On the other hand, the device is only very partially successful against strays, which is also the case with Marconi's device. To explain the operation of the device I shall consider

Digitized by Google

Figure 12. This represents the well-known direct current characteristic of the carborundum-steel detector. As is generally known, the best working conditions are obtained at the bend B of the positive part of the curve, say for an additional applied e.m.f. of $+V$ volts. The best value of V depends to some extent, on the strength of the incoming signals.

If we apply instead of the positive e.m.f. $+V$, a negative e.m.f. $-V$, we see that the additional alternating e.m.f. $2A1$, will give no response whatever, since the areas of $A2b$ and of $A1a$ are equal and opposite in sign. A loud signal, therefore,

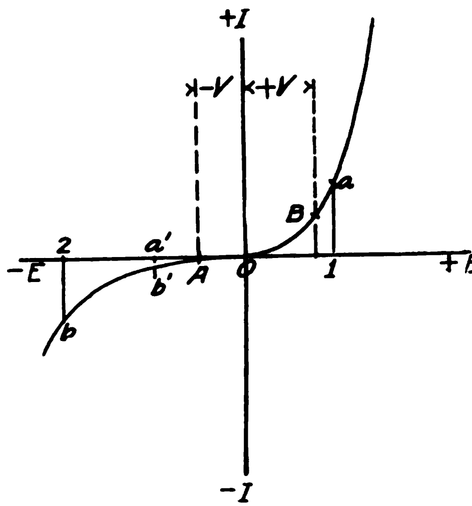


FIGURE 12—Characteristic of a Carborundum-Steel Detector

gives *no response*, altho a weak signal does. For instance, a signal of one-third the former amplitude, $a'AO$, will give the response corresponding to the resulting negative area $Aa'b'$.

We see that we have no reception of strong signals but at the same time a perfect reception of weak signals. We can cut out very powerful interfering stations in this way. It is clear from Figure 12, that the stronger the interfering signal is, the higher the negative voltage which must be applied to cut out interference perfectly. Since on the other hand the loudness of the signals for which reception is intended, depends largely on the value of the applied negative e.m.f., the best working conditions are obtained for the value of $-V$ between 0 and 2. The arrangement works best for the *very strong*

Digitized by Google

interfering signals which are compensated for by this large negative voltage. The arrangement is thereby best suited to long distance stations, situated near harbors or other centers of heavy traffic, and consequent interference.

The effectiveness of the arrangement against strays is quite clear since Figure 12 shows that the weaker the signal, the smaller the response, proportionately speaking. For strong signals the response becomes zero. While for excessively strong signals the response begins again, the rectified current is in the opposite direction to the applied constant e.m.f.

(b) Another arrangement was tried, which was effective only against interfering stations to some extent, but did not weaken incoming signals at all. Tho the arrangement is of no use against strays, it is briefly described here since it is useful in many cases.

The Landangan station, when receiving from Oiba on the 1,600 meter wave and working on the large antenna, was always interfered with by ship stations in the harbor of Panaroekan, 15 km., (9 miles) distant, and Soerabaie, 180 km., (110 miles distant) on the 600 meter wave. This interference was overcome in some tests by tuning a small antenna (which is referred to in the description of the stations) to the interfering 600 meter waves. As soon as this was accomplished, the interference was practically eliminated especially when resistance was introduced in the smaller antenna so as to make the damping of both antennas the same. This tuning was very sharp; and the success of the arrangement was not due to a screening action since the two antennas were not in the same line with the interfering station. The action must be due to compensation of the incoming interfering signals in the main antenna by re-radiated energy from the compensation antenna.

(c) The third arrangement, which was tried, was in the direction of the elimination of strays, and its diagram is given in Figure 13.

Two receiving antennas, L_1, L_2 of the same shape and dimensions, were installed near enough together (10 or 20 meters or thirty to sixty feet apart), to make them respond in the same way to strays. (For the aperiodic disturbances, this distance could be easily increased, but for periodic disturbances, the distance of separation must be small compared to the wave length of the strays, in order to get the induced e.m.f.'s in phase.) On the other hand, the antennas must be placed sufficiently far

Digitized by Google

apart so that signals set up in the one which is made aperiodic (L_2) shall not cause currents in the tuned antenna (L_1).

One of the antennas, L_1, is tuned to the incoming signal and coupled to the detector circuit D_1 in the ordinary way. The detector D_1 will rectify signals as well as strays and send the rectified current into the telephone; or, as in the case of the drawing, into the differential transformer T_r. The antenna L_2 is tuned either to the same, or preferably a longer wave

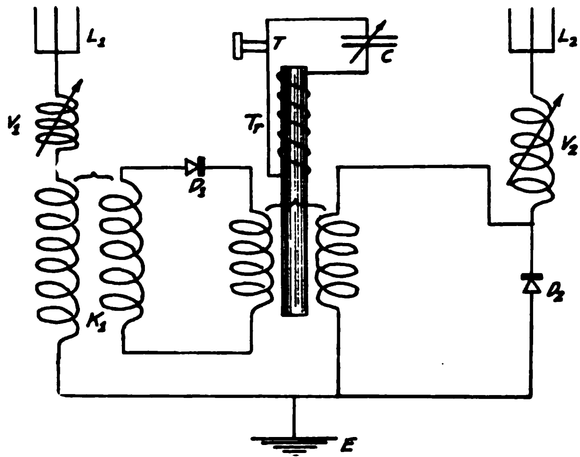


FIGURE 13—Compensation of Periodic Strays at Audio Frequencies

length, thus making it less sensitive to the signals and more sensitive to the long wave strays. The detector D_2 is switched directly into this antenna, thus making it aperiodic or nearly so. This arrangement makes it almost impossible to receive any distant signal on the antenna L_2, but loud signals on wave lengths different from those to which L_1 is tuned and strays give a response that is nearly as loud as can be obtained on the tuned antenna L_1.

The rectified current is sent to the same telephone mentioned before; or, as in the case shown in the drawing, to the differential transformer T_r. However, this second current from the aperiodic antenna, L_1, is arranged to act in the opposite direction from that of D_1. The telephone T is either connected in series with D_1 and D_2; or, as in the drawing, in a third winding of the differential transformer and in series with the condenser C to permit tuning to the spark frequency. Since D_2 does not respond to distant signals, there will be heard in the telephones

Digitized by Google

the signals from D_1 only, whereas the strays rectified by D_1 and D_2 tend to compensate. By varying the coupling K, this compensation can be made complete.

This device will only permit complete compensation of strays of different loudness when the characteristics of both detectors D_1 and D_2 are similar. This is easily accomplished by using carborundum crystals with the best applied e.m.f. As soon as this is applied, the characteristic for rectified currents as plotted against incoming alternating current is almost a straight line. This scheme was tried in practice but since the two equal antennas were not available, compensation could be obtained only for rather weak couplings, K, with a consequent loss of signal strength. The results were encouraging enough, however, to warrant repeating the trials on a larger scale, and with proper apparatus. The results of these more elaborate and confirmatory tests, will be published in the PROCEEDINGS within a short time. I am entirely convinced that this compensation device, combined with the Dieckmann cage around the antenna to cut off aperiodic strays, solves the problem of the elimination of strays. It will be seen that the same principle of compensation just described for the rectified or audio frequency currents is available too for the radio frequency currents. However, the currents to be compensated for in this case must be of the same frequency, decrement, and phase, thus introducing difficulties not encountered with audio frequency compensation. For audio frequency compensation, it is sufficient that both rectified currents should be equal in frequency. Radio frequency compensation requires two antennas tuned to the same wave length and close together, and having the same decrement. Consequently, in this case, the use of an aperiodic compensating antenna is not possible.

In order to get compensation at radio frequency, two antennas of the same size and wave length must be used, one of which is more sensitive to incoming signals than the other and both of which must be equally sensitive to strays. This could be done by having a directive aerial pointed toward the receiving station, and either a directive antenna in the minimum receiving position relative to the sending station or a non-directive antenna for compensation. In both cases, a great loss of signal strength will be involved, since the compensating antenna will not only compensate strays but also the incoming signals to at least a large extent. I therefore prefer compensation of the rectified audio frequency current rather than radio frequency compensation.

Digitized by Google

Part 4. The Author's Suggestions Relative to the Origin and Propagation of Type 3 Strays

Since the theory of Dr. Eccles' does not hold good for this type of strays, I attempted to suggest another solution. To begin with, it is necessary to consider the curves of daily and monthly variation of strays. In Figure 14 are given the curves of daily variation, averaged over every month of the year, for all strays received during the daytime at the Landangan (Siteo-bondo) station. The year during which the observations were made began in June, 1913 and ended in June, 1914. The averages for these two years (that of June, 1914 being dotted) agreed very well.

The strays indicated by the letters "*Ls*" are plotted vertically in accordance with their scale of values from 0 to 5 as given in Part 3 of this paper. The average value for every hour of the day (in true solar time of the place under consideration) is the heavily drawn black line. The dashed lines indicate the limiting (that is: the highest and lowest) values observed during the hour in question.

We see that altho the average line could be drawn for the daily variation, the individual values during the same hour on different days in the months may be widely divergent on both sides of the average. It is clear also that morning and afternoon curves are symmetrical only for those months of the year during which the altitude of the sun is a minimum (that is: June, July and August). Symmetrical curves of this type are common for European stations.

These months of maximum sun's altitude covered the period of the latest trade wind (or east monsoon); and we shall call the daily variation curves during these months, the "east monsoon characteristic." We shall indicate this type of characteristic by the sign $\smile$, meaning that during these months, strays slowly fall from the sunrise point $\underline{o}$ to noon and then slowly rises until sunset $\bar{o}$. It will be seen that the characteristic for the month of August is already changing into a second type of characteristic, and that a change is also occurring during the month of May. It is only during these months that the stations fully fulfill their contract.

As the altitude of the sun increases, it will be noticed that the characteristics continually change, not so much in the morning but chiefly in the afternoon. The characteristic then becomes of the general shape indicated by its sign $\_\frown$ as found in the characteristics during the months of September, October,

Digitized by Google

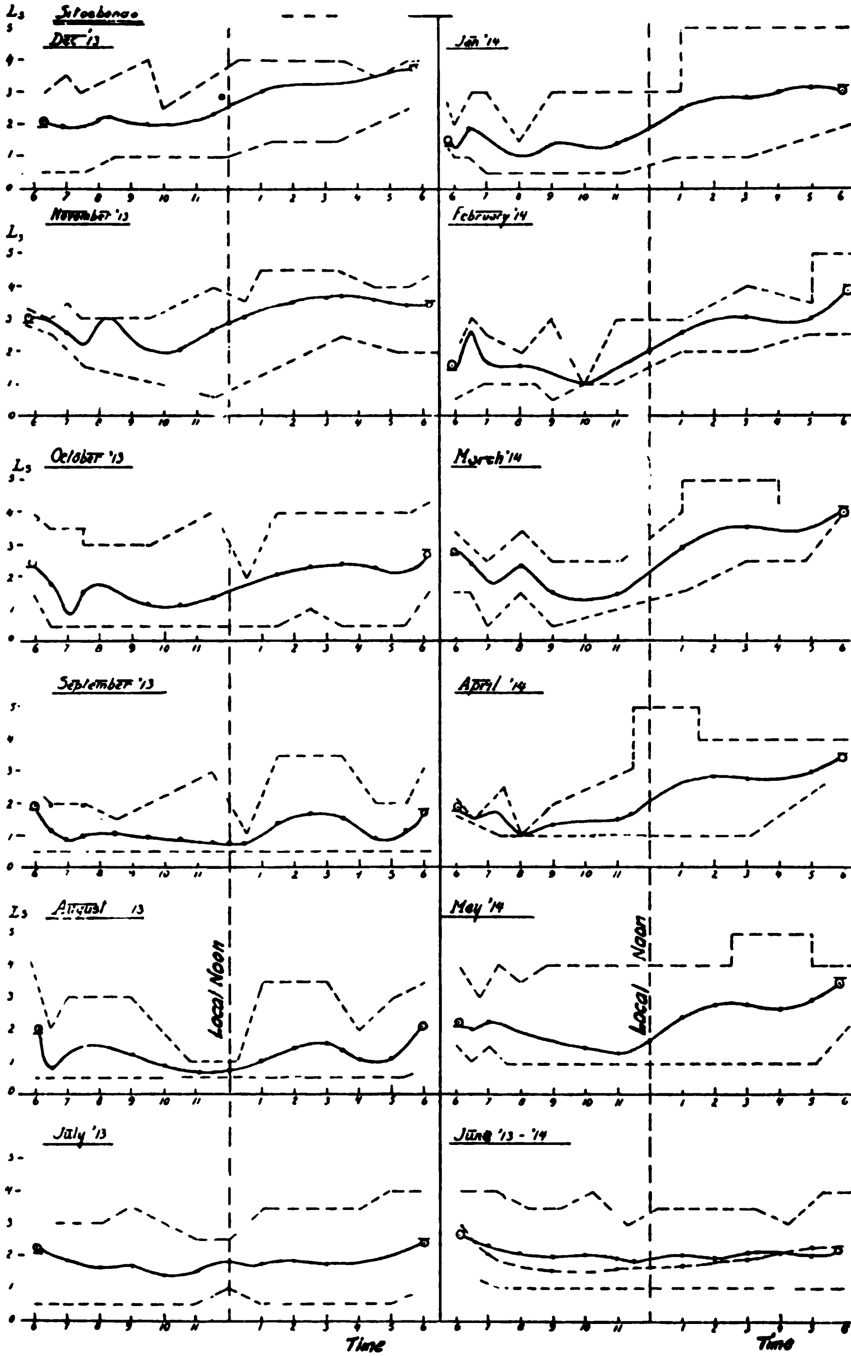


FIGURE 14—Daily and Monthly Variation of Strays

Digitized by Google

March, April, and May. As has been stated August is of an intermediate form. This characteristic we shall call the "intermediate period characteristic." It is found during stormy periods when neither of the two types of trade wind dominates. On the average, communication is possible in the morning during these months, but during the afternoon contractual requirements could not be met.

With the latitude of the sun still increasing and the west trade wind (the west monsoon) becoming permanent, the characteristic takes the form indicated by its sign ∽, with high values in the morning during the months of November, December, January, and February. During some days in this period, no communication can be handled, since the signals also fade in intensity as do the strays in the morning.

We shall study hereafter, the meaning of the signs employed in these characteristics.

Figure 15 gives the average daily variation over the whole year, with night observations included. It must be admitted, however, that the dashed portion of the night curve is to be critically considered, since not many observations were available

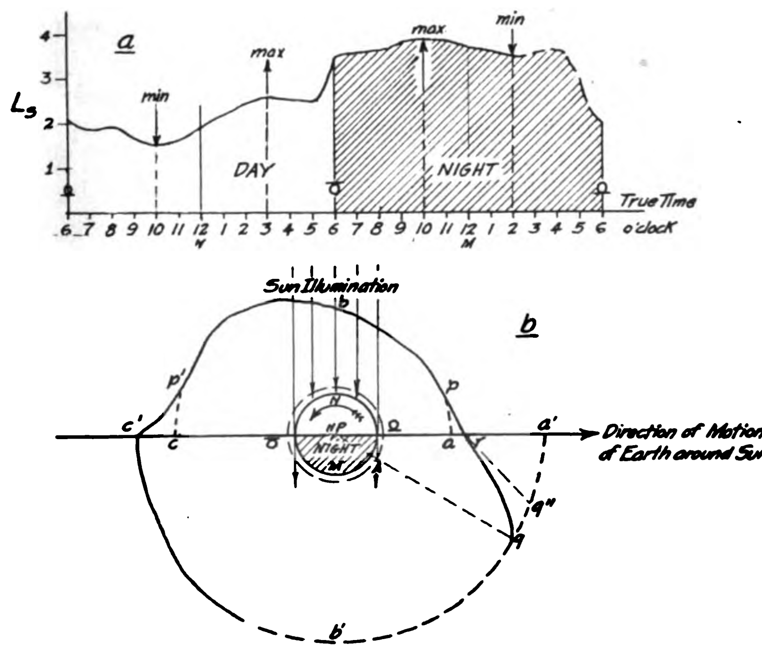


Figure 15—Average Daily Variations of Strays Thruout the Year

during such times, the stations being generally closed during that part of the night. We see that the average day of the year gives a high value during the night time for the stray intensity; (namely, class 4; that is, requiring a signal strength of 250 to 500 times audibility for satisfactory communication). About two hours before sunrise, the strays began to weaken until at 10 o'clock in the morning, the minimum is reached. Then the strays increase until three in the afternoon, remain almost constant until an hour before sunset, after which they rise sharply to the night value.

It is easily seen that there is enough difference between day conditions (and especially morning conditions) and night conditions to enable us to conclude that if the theory of Eccles were correct, our stations on the average, are not situated near the thunder storm center. On the other hand, it would seem that in the afternoon, we were rather near such a center, the difference between average afternoon and night observations being only small. This already indicates that the phenomena are not governed by so simple a supposition as that of Eccles. In Figure 15 there is also shown the same curve of daily variation of stray intensity thruout the year plotted in polar co-ordinates around the circular cross section of the earth. The direction of the impinging sun beams and the direction of rotation of the earth around the sun are given.

We see that the polar diagram shows two curious half-oval curves of different sizes for the day and night observations (*abc* and *a'b'c'*) symmetrically arranged relative to the direction of motion of the earth around the sun and connected by the steep lines (*pq* and *p' q'*), these steep portions occurring near sunrise and sunset.

It is quite clear that the night phenomena are the symmetrical repetition of the day phenomena; and that the reason for the difference between night and day must be found, in all probability, in the medium between the point of origin of the strays and the receiver which is under the influence of the radiation of the sun. We find this same influence, in a much more pronounced form, in the propagation of the electromagnetic waves of the radio transmitter; and I proved elsewhere that the difference must be due to ionization of the air layers up to a height of some 200 km. (125 miles).

In this connection, it is interesting to note from the polar diagram of Figure 15 that the diminution of strays at the point *A* begins long before the time of sunrise at the place in question.

Digitized by Google

That is, as soon as the layers in the atmosphere above the place are touched by sunlight, the change begins.

This indicates that the source of strays is not (as Eccles supposes) in the lower layers of the atmosphere, since the difference between night and day would, in that case, begin only as soon as the lower layers between the source and receiver are reached by sunlight. The assumption of the source of the strays in the higher layers of the atmosphere is therefore logical, and under these conditions, the difference between day and night strays is natural and to be expected.

Another interesting fact in connection with the shape of the polar curve of Figure 15 is that the strength of strays is not a function of the direction of the impinging *sunbeams* but that the curves are symmetrical relative to times determined definitely by the movement of the earth around the sun. This furnishes a hint as to the manner in which the higher layers of the atmosphere may become the source of disturbances.

In its course around the sun the earth frequently is struck by cosmic particles which give rise to disturbances in the electric conditions of the upper layers of the atmosphere. It is clear that the disturbances must be different on different parts of the layer; and this difference between collisions in front of the earth and those in back of the earth (as referred to the earth's motion) would give rise to the oval form of the diagrams.

These oval curves would be easily explicable if we assume as the source of strays an atmospheric layer of considerable height which is disturbed by the irregular bombardment of cosmic particles of dust or is disturbed in any other plausible fashion. Tho the theory of cosmic bombardment of upper layers appears to me to be the most plausible origin of strays of type 3, particularly since such a source of strays would explain also the cause of daily variation in the strength of the earth's magnetic field, nevertheless, we are not sufficiently well informed concerning the upper layers of the atmosphere to be able at this moment to give a definite proof of my assumption.

If, therefore, I base my explanations of the strays of type 3 on the above mentioned proposition, it is rather because it seems to me quite a plausible explanation than because it can be absolutely proven to be the truth. If this high layer is the source of strays of type 3, it is quite clear that not only the point directly over the station (that is, the zenith) can be the source of strays; but that in every case, the changes in electric conditions in the circular segment of this layer the center of which is

Digitized by Google

the zenith of the station will contribute to the strays observed at the station under consideration. The nearer the point of disturbance to the station zenith, the more pronounced will be the disturbance.

It is, of course, of some interest both practically and scientifically to note the approximate radius of the segment above mentioned, since this will give us an indication of the range of strays of type 3 and of the limiting possibility of distance at which strays of type 3 may be heard simultaneously in different stations.

Of course, the type of receiver used alters this effective stray radius, and it is well known that with very sensitive receivers, not only the *loudness* of the strays increases but also that the *number* of strays received every minute also increases, thus showing that in the latter case, we detect more distant stray centers.

For the detector and receiving set used for the observations in the Indies, which receiver has been briefly described in Part 2 of this paper, the average range of strays of type 3 can not be definitely determined.

On examining the oval curves of Figure 15, it can be clearly noted that the average diminution of the night strays into the day strays (as averaged over the entire year) is complete only at the point p; that is, one hour after sunrise at the receiving station. Similarly the increase of day strays to night strays begins as early as p'; that is, one hour before sunset at the station under consideration. This shows clearly that the illumination by sunlight of places one hour distant from the station in question causes a limiting effect, which is just detectable by means of the resulting change in strays at the receiving station, if receivers are used of the type described. The range of these centers of stray origin, or the radius of the segment mentioned, is therefore the distance of rotation of the earth in one hour; that is to say, $1/24 \times 40,000$ km., or 1,670 km. (1,000 miles). In other words, stations with receivers of the type employed at our station and separated by a distance of 3,340 km. (2,000 miles) might expect to detect some strays of type 3 at the same moment; but in this case the strays would be faint to the limit of audibility. On the other hand, if the stations are 1,670 km. (1,000 miles) apart, and the stray originates just above one of the stations, this station will detect it very loudly and the other station will detect it as just audible.

This is the reason why during tests intended to study simul-

Digitized by Google

taneous strays at different stations, the stations must be quite close to each other in order to detect simultaneously and continuously the same strays at the same time, as the researches carried out by Dr. Eccles showed.

Under these conditions, each station hears the most powerful groups of strays. The conclusion drawn from these results has been used erroneously to prove Dr. Eccles' theory of the lightning origin of strays. Since, however, strays of type 3 were dominant and since the range of strays from lightning is not very large, the method of simultaneous station observations will yield only slight results.

In the light of my theory concerning type 3 strays, loud groups of such strays mean that the point at which strays are originating in the upper layers of the atmosphere is near both stations; that is, at a distance considerably less than 1,670 km. (1,000 miles). Furthermore, simultaneously heard loud signals indicated, in addition, that the source of strays was not very far from the point half-way between the stations. It is quite clear that these conditions are only fulfilled for stations not more than at the most about several hundred km. (or miles) apart. The extreme limit is estimated by me as approximately 1,000 km. (600 miles). Also all other centers of type 3 strays around the stations will produce responses in both stations which undoubtedly occur simultaneously but will be so different in strength, because of the difference in distance, that these stray interruptions will never give the impression of simultaneity. Lastly, the apparent similarity of strays at the two stations will be still further spoiled by the reception at each station of strays which are inaudible at the other.

The correctness of the previous reasoning is strictly confirmed by the fact that, tho Figure 15 shows a range of the strays at 1,670 km. (1,000 miles) during the day time, no simultaneous strays could be observed at our three stations which were only between 890 km. (550 miles) and 1,610 km. (970 miles) apart; and this was the case even at night.

On the other hand, tho not simultaneously occurring, the *average* daily curve of strays was not much different for the different stations. This was to be expected from my theory, the different stations being sufficiently near together to be under practically the same average influence of the layer above them, and this small part of the total layer is struck by a nearly constant number of cosmic particles.

All of these effects agree with the theory here given and

Digitized by Google

militate against the correctness of the theory of the lightning origin of strays, as do also the demonstrations with the Dieckmann cage. On the other hand, it is possible from the consideration of the point q of Figure 15, where the diminution of night strays to day strays begins, to approximate the *height* of the *disturbed layer.*

The diminution from night strays to day strays begins as soon as a point of the upper layer some 15° sunward (that is, to the east) of the station under consideration is reached by sun beams. We must also remember that this distance of 15°, which equals one hour of earth rotation, was found to hold during the day time (at points p and p'). The distance between the station and the most distant perceptible centers of strays at night is larger since the propagation of strays is then better. We are at a loss, however, to determine what value shall be taken for the better transmission at night; consequently we shall assume a minimum distance; that is, 15°, and equal to that during the day. We shall see that by so doing, the layer height as calculated will be too large.

From Figure 15, we note that the decrease of strays begins about 2.5 or 2 hours before sunrise. The exact moment is not quite certain because, between these times, the dashed portion of the curve is not absolutely trustworthy. From these figures, and taking a more frequent radius of the stray circle to be one hour or 15°, we find that the first sun beam, after touching the earth (see beam A of Figure 15) reaches the upper layer at a point directly above the station, provided the station will have its sunrise 1.5 to one hour afterwards.

If in Figure 16, E is the earth, L the upper layer, A the zenith point of the station, a, which is reached by the first sun ray, then we can calculate the height h of the layer from the formula

$$h\,(2r+h) = R^2 \tan^2 a,$$

and since H is small compared with $2R$

$$h = \frac{R}{2} \tan^2 a,$$

in which R is the radius of the earth. For $a = 1$ to 1.5 hours $= 15°$ to 22.5°, the height h is found to be between 225 km. (140 miles) and 540 km. (330 miles).

It is an interesting confirmation of this theory that in the neighborhood of the first value given (that is, between 180 and 200 km.) (110 and 120 miles), a layer of the type mentioned

Digitized by Google

has been predicted by scientists in many fields. This layer, the *Heaviside* layer, is supposed to be a sharp frontier surface between the lower poorly conducting layers of the atmosphere and the highly conductive atmosphere above it. This layer is supposed to give rise to reflection phenomena in radio transmission at night, and is supposed also to be a seat of the cause of alteration in the earth's magnetism. This height has also

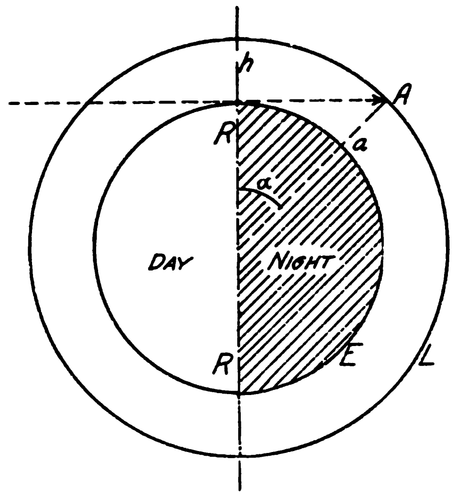


FIGURE 16—Location of Centers of Stray Origin

been estimated to have the value stated from observations on the incandescence of meteors and also from the aurora borealis. On another occasion[4] I showed that phenomena in the night propagation of radio waves not only sustained this calculation but I showed also, from the "silent belts" in radio transmission at night, that the height of the layer was about 200 km. (125 miles). This value corresponds very well with the values of between 225 km. (140 miles) and 540 km. (330 miles) found for the height of the layer which produces strays of type 3. The excessively largely value of 540 km. (330 miles) can be easily explained by remembering, as before stated, that the radius of the segment of stray centers is not 1,670 km. (1,000 miles) as during the day, but much larger.

Taking the layer as being at the height of 180 km. (110 miles)

[4] In a dissertation for the degree of Doctor of Science, May 18, 1916; and in "Jahrbuch der drahtlosen Telegraphie" (not yet published).

Digitized by Google

we get for the angle α in the equation above 13.5°, which is equivalent to the angle traversed in 54 minutes of time by the earth's rotation, so that the radius of strays at night time would be 2.5 (or 2) hours minus 54 minutes, that is, between 1 hour and 36 minutes and 1 hour and 6 minutes. This corresponds to an effective range of night strays of from 2,670 km. (1,640 miles) to 1,750 km. (1,080 miles), as against 1,670 km. (1,000 miles) during the day time.

This is quite possible, as shown in Figure 15, since the average loudness of strays at night is about 1.5 times that in the day time, so that there can be no objection to taking both the day- and night-stray-originating layers as existent and identical.

A further reason for these conclusions is the fact that the daily variation in strays, as given in Figure 14, is quite similar in character to the curves of variation of the earth's magnetism as I saw them published in the "Wireless World" (or "Marconigraph") some time ago, which latter variations are attributed to eddy currents in the Heaviside layer. By supposing this layer to be the "secondary" source of strays of type 3, we obtain a sufficient explanation for the daily changes in the strays, these variations being analogous to those of the earth's magnetism. On the other hand, the gradually altering form of the daily characteristic, as it changes in accordance with the symbols given, from ◡ thru _⌒ to ◡⌒, is easily explained if we regard the cosmic bombardment as occurring chiefly in the plane of the earth's orbit. It was found that the type of stray corresponding to the symbol ◡⌒ occurred whenever the angle between the sun's declination circle and the latitude circle of the station under consideration did not differ more than 10°. Similarly, the type _⌒ occurred for a difference in this angle of 10° to 20°; and when the difference exceeded 20°, the symbol was ◡. It is for this reason that strays in Europe are nearly constant over the entire day (strays from lightning sometimes excepted). In the case of the ◡ characteristic, the distance to the strong centers of cosmic bombardment is very large, and the strays are therefore weak. This is why strays of type 3 are so heavy in the tropics and so weak in Europe. At the poles we assume that they would be almost not noticeable. It remains to determine, however, in what way disturbances in the Heaviside layer produced strays in the antenna. This is not a difficult matter to explain, and the explanation will at the same time clear up the difference between the day and night strays of type 3.

Digitized by Google

The Heaviside layer is a conductor, as also is the earth. Between these two conductors, we have a layer between 180 km. (110 miles) and 250 km. (120 miles) thick, which is a non-homogeneous dielectric. This dielectric is fairly perfect during the night, as is indicated by the goodness of night communication; but it is rather an imperfect dielectric during the day, the conductivity changing with the height above the earth. This complex dielectric forms a large condenser almost free from losses during the day but rather imperfect at night. The cosmic bombardment by charged particles on the upper layer will be detectable thruout the dielectric; and this to a greater degree during the night than during the day. On the other hand, in the latter case, part of the effect is lost because of the imperfect character of the dielectric, and hence the difference between day and night conditions.

It must be remembered that the antenna is electrically connected to the earth (either conductively or capacitively), and that it will therefore be disturbed by all changes in the field or potential gradient of this condenser. Such changes depend upon the charge of the cosmic particles, or on other causes of excitation of the upper layer, as well as on the original charge of the condenser. This latter charge is the reason for the influence of the seasons on the strays, which point was not mentioned heretofor. It has already been stated that the light of the sun (and consequently the time of the year) influenced markedly the daily characteristic as expressed by the symbols ⌣, ‿⌒, ∽.

In Figure 17, there are given the month by month characteristics for each of the three stations over a whole year, these being obtained from the average values at noon, over every month.

The times when the sun's altitude is 90° for the place under consideration are also given. We see that these occur twice a year for every station. Tho the symbol for every station is then ∽, we see, on the other hand that the points of *maximum strays* do not come at the same time but that there is a lag of as much as 1.5 months between 90° sun altitude and maximum strays.

We see that the maximum strays follow the monsoon or trade wind seasons of the year much more closely, the maxima always occurring at the time just between the west monsoon and the "intermediate period"; whereas the minimum always occurs during the east monsoon and close to the end of this season when it is passing into the intermediate period. The signs

Digitized by Google

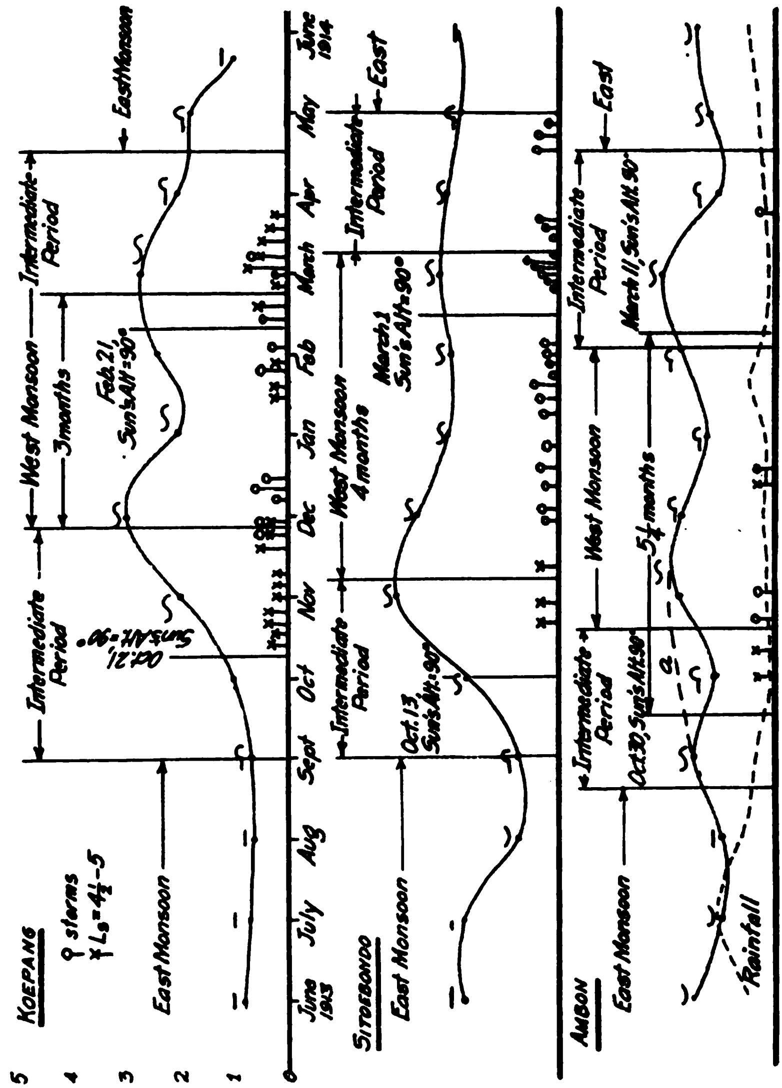


FIGURE 17—Yearly Variation of Strays

◡, ‿⌒, ◡⌒, correspond to the general aspect of the daily variation curve as taken from Figure 14 for the months to which they are assigned in Figure 17. In fact, the Director of the Meteorological Institute of Batavia assured me that the maxima of strays found by my observations correspond to the maximum increase in potential of the earth's field. Consequently, we have here located that original charge of the earth condenser which is the reason why, even tho disturbances of the upper layer do not alter with the sun's altitude, changes in the strength of their fields and consequently changes in strength of the strays produced must be dependent on the season.

In concluding this paper, I may state that inasmuch as type 3 strays do not originate in lightning, their maxima do not coincide with those of thunder storms either near the stations or distant from them.

In Figure 17, thunder storms and very heavy strays of the thunder storm type, were indicated by the symbols ♀ and ϒ, the length of the vertical line giving the duration of the outburst of strays on a certain scale.

We see that for all three stations, the periods of thunder storm, ♀, were preceded by heavy strays, ϒ, of type 1. These strays did not occur simultaneously at the three stations, which is the best proof that their range is short. For the station at Keopang (Oiba), it might be stated that strays of both classes occur almost simultaneously, tho the thunder storm, ♀, occurred most nearly at the middle of the west monsoon period, where the type 3 strays have no maximum whatever.

For the Landangan (Siteobondo) station, the difference just mentioned is still more striking, and of the same type. For the Ambon (Noesanivé) station, it is even more evident that there is no connection between the two classes of strays. It is obvious that both are to be considered separately, and compensated for in different ways.

Other atmospheric conditions were shown not to have any influence on the strength of strays. Of course, thunder clouds coincided with strays of type 1 and low-lying rain clouds with type 2. In spite of the common belief, rainfall in itself has no influence on strays, at least so far as types 1 and 3 are concerned. This is clear from the curves for Ambon, in Figure 16, where are shown the strays and at the same time, the dotted rainfall curve.

Digitized by Google

SUMMARY: Following a general discussion of radio vs. submarine cable telegraphy, the work of the Radio Division of the Dutch East Indian Service is described.

A chain of stations installed for this Service are considered; their location, equipment, and operation being described in considerable detail. The failure of the original contractor to furnish stations covering the requisite distances (which would have required six to eight times the actual available power) is critically considered.

The choice of station location and certain details; e. g., precautions against earthquakes, are then treated.

A description of the origin and nature of strays and their classification is given; together with a number of methods for their elimination. In this connection, the Eccles' theory of a tropical thunder storm origin of all strays is disproven. There are described, in addition, some special methods of reducing strays, methods intended especially, however, for the elimination of undesired, powerful, and interfering signals.

Strays fall into three classes, the origin, character, and mode of elimination of which are as follows:

Type 1: Strays originating in nearby thunder storms, of short range, of periodic electrical character, audible as sudden and loud widely separated clicks, and eliminated by radio or audio frequency compensation circuits.

Type 2: Strays associated with low-lying rain clouds, of very short range, of intermittent uni-directional electric character, audible as a constant hissing sound, and eliminated by the Dieckmann electrostatic shielding cage.

Type 3: The most common or night strays, originating in cosmic bombardment of the Heaviside layer, of audible range of several hundred miles (with the receivers used), audible as a continuous rattling noise, and eliminated by the Dieckmann cage.

The daily and seasonal variation of strays is considered in great detail, and a number of interesting conclusions are drawn.

Digitized by Google

Roy A. Weagant: 1. Dr. de Groot's paper has certainly been of very great interest, yet there are many points contained in it which I am unable to accept. It seems to me fundamentally impossible that the shielding cage which he has used can work for the very simple reason that if you surround an antenna with a conducting structure of any kind, regardless of whether it is aperiodic or has a period of its own, it will have currents set up in it when acted upon by electromagnetic waves. Constructed as indicated by Dr. de Groot, this cage would have an extremely strong electromagnetic and electrostatic coupling to the antenna, consequently any currents set up in the shielding structure will induce currents in the antenna itself and I see no possibility of avoiding this result.

I might say in addition that my personal experience with arrangements of this kind have not produced any useful results.

The use of the balanced crystal or single crystal having current applied in the direction the opposite to the direction of rectification has some advantages. This has been quite fully developed by Mr. Round of the Marconi Company but its action is to limit the maximum response and thus save the operator from the disturbing effects of the loud crashes.

Dr. de Groot's scheme of using reverse potential on the crystal is really equivalent to selecting a crystal of the particular necessary characteristic and using the battery potential in the ordinary direction. This arrangement, however, can in no sense be considered a stray preventer.

Dr. de Groot also shows an arrangement of two antennas having the currents developed in the audio frequency circuit opposed. I am entirely unable to credit this arrangement with any successful results as I have tried it many times and, furthermore, a complete analysis of the actions involved, which is too lengthy for this discussion, does not indicate even theoretical possibilities. I do not quite see how insertion of a resistance in one of the antenna circuits referred to can be expected to secure the results stated since we know perfectly well that its effect would be to reduce both the stray and the signal in proportion, therefore when the audio frequency circuit attached to this antenna is opposed to the audio frequency circuit attached to the other antenna, the available energy from the stray will be of the same reduced order as the energy from the signal.

Dr. de Groot has stated that, when in the use of this arrange-

Digitized by Google

ment the opposition took place in radio frequency circuits, accurate phase adjustment was necessary, but was not necessary when the audio frequency circuits were opposed to it. It seems to me obvious that in either sort of circuit where opposition effects are desired, correct phase adjustments are essential. The employment of circuits tuned to the group frequency of the incoming signal, as suggested in this paper, is an obvious fallacy to anyone who has made use of them. Such a tuned audio frequency circuit simply responds when struck by a stray impulse in its own period in the same way that a tuning fork vibrates from the blow of a hammer with the result that "musical" strays are produced. This is very much more disturbing and difficult to read thru than the response ordinarily heard from strays since it has the same note as the signal itself. Dr. de Groot's theory as to the source of that particular sort of strays which we have all recognized as being the most difficult to overcome is interesting but I am unable to reconcile it with the daily and seasonal variations in stray intensity which are commonly observed. It might, of course, be one of several contributary causes, but hardly the sole cause.

Another point which the paper makes is that these strays do not occur simultaneously at two or more stations of the author's system. This is rather a curious observation because of its disagreement with observations in this part of the world which have indicated to a considerable extent at least the simultaneous occurrence of stray discharges at widely separated points. For instance, it has been quite common to note that the same word or letter which was lost by a station in the British Isles from a transmitting station on the American continent was also lost at another station on this continent. There is, however, sufficient information available to indicate that in all probability both sorts of conditions obtain, the actual condition varying much with the location of the stations.

Alfred N. Goldsmith: The Dieckmann cage, as used by Dr. de Groot, is obviously a device of great utility in the elimination of strays. A further explanation of its action, supplementing that of the paper, is not amiss.

1. It is first necessary to consider the elementary action of the *Faraday cage*. It will be at once recalled that Faraday demonstrated conclusively that the electric field inside a closed conducting surface was absolutely zero. The experiment was the following. A cube of wood covered with tin foil, and about

Digitized by Google

6 feet (2 m.) on a side was built and mounted on insulators. The observer got inside the cube with the most delicate gold-leaf electroscope available. The tin foil was then connected to one terminal of a static machine, and charged until huge sparks brushed off all the edges and corners of the cube. Nevertheless, the electroscope did not indicate the faintest trace of any separation of the leaves, and evidently the cube acted as a *complete shield for all electric forces proceeding from charges on its surface.* The arrangement is shown in Figure 1.

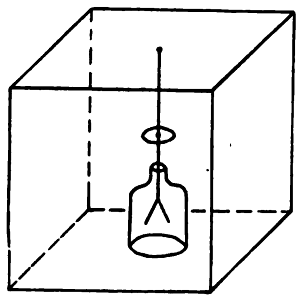


FIGURE 1—Faraday Shield

It is clear, therefore, that if such a cube surrounded an antenna the antenna would be entirely protected from all charges on the surface of the cube; and if this surface of the cube were grounded, charges passing over the surface of the ground or local distortions of the earth's electric field could not possibly affect the antenna electrostatically.

On the other hand, using this brutally simple shield, the antenna would be altogether too efficiently protected, inasmuch as it is well known that the electromagnetic waves of the incoming signals would be prevented from reaching the antenna by a solid metal sheet. So far, then, but little progress has been made; and we are forced to seek further expedients.

2. I quote now from Hertz's classic work on "Electric Waves" in connection with .the polarisation of short electromagnetic waves.

"From the mode in which our ray was produced we can have no doubt whatever that it (the radiated wave) consists of transverse vibrations and is plane-polarised in the optical sense." (The wave was produced by an ordinary linear Hertzian oscillator or doublet, the length of which lay on the focal line of a cylindrical

Digitized by Google

metal mirror.) "We can also prove by experiment that this is the case. If the receiving mirror be rotated about the ray as axis until its focal line, and therefore the secondary conductor also, lies in a horizontal plane, the secondary sparks become more and more feeble, and when the two focal lines are at right angles, no sparks whatever are obtained even if the mirrors are moved close up to each other. The two mirrors behave like the polariser and analyser of a polarisation apparatus.

"I next had made an octagonal frame, 2 meters (6 feet) high and 2 meters broad; across this were stretched copper wires 1 mm. (0.04 inch) thick, the wires being parallel to each other and 3 cm. (1.2 inch) apart. If the two mirrors were now set up with their focal lines parallel, and the wire screen were interposed perpendicularly to the ray and so that the direction of the wires was perpendicular to the direction of the focal lines, the screen practically did not interfere at all with the secondary sparks (that is, with the passage thru it and subsequent reception of energy). But if the screen were set up in such a way that its wires were parallel to the focal lines, it stopped the ray completely . . .

". . . When the primary oscillator is in a vertical position the oscillations of the electric forces undoubtedly take place in the vertical plane thru the ray, and are absent in the horizontal plane . . ."

That is, Hertz demonstrates conclusively that a number of parallel wires (with separation considerably smaller than the wave length) entirely stop the passage of electromagnetic (plane polarised) waves whenever the wires are parallel to the electric force in the wave front, but *do not impede the passage of the waves at all when the wires stretch perpendicular to the electric force in the wave front.*

3. Coming now to Figure 2, it will immediately suggest itself to the skilled radio engineer that it is possible to effect an operative combination of the Faraday shield against changing electrostatic fields or movement of external charges with a Hertzian screen permitting the passage of electromagnetic waves. The combination is the elementary Dieckmann cage referred to, and is given in Figure 2 if we regard the faces as made up of horizontal wires connected together in such a way that they are all at ground potential and if these wires are also perpendicular to the electric force in the front of the advancing signal wave. This screen will therefore act as a perfect shield against charges or field alterations outside, since even if these charges are on its

Digitized by Google

own surface they can have no effect within. On the other hand, if the advancing electric field has the distinctive feature of a true electromagnetic wave, it can pass thru into the cage. This will be the case, since if X is the direction of transmission of the signal wave, E, the electric force will be vertically up or down.

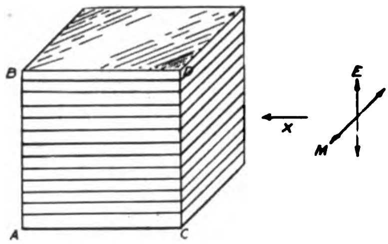


FIGURE 2—Hertzian Cage

To summarise, then, such a combined Faraday shield and Hertzian transmitting screen will *permit the passage of advancing signal waves* (or other true electromagnetic waves) while *absolutely shielding the interior from potential variations arising from moving charges* in the vicinity of the cage *or variations in the field of the earth.*

4. An objection would, however, be at once advanced against the elementary Dieckmann cage shown in Figure 2. The vertical edge wires, AB, CD, etc., which keep the entire sides at ground potential are parallel to the antenna within, and they would most certainly absorb a dangerously large portion of the incoming wave energy, being, in fact, themselves grounded antennas. This objection is satisfactorily met by Dieckmann thru the use of the arrangement shown in Figure 3. This is a side view of a shielded vertical antenna, the horizontal lines (with the short jumps in them) being representative of squares of wire around the antenna A and in a horizontal plane. These squares are kept at ground potential by means of the resistances R and the conductor S. These resistances in question keep the conductor S from periodicity, and the incoming waves can set up in it only feeble oscillations and consequently there will be but slight energy absorption therein. How feeble this absorption is will appear further in this discussion in connection with another aspect of the problem. We may say, then, that even the *grounding edge wires* can be arranged, *by insertion*

Digitized by Google

of more than the critical resistance, so that they *will absorb practically none of the incoming energy.*

5. One further possible objection to this system of shielding remains to be considered. Suppose that from some cause (which is so extreme as to be absurd and will never be encountered in practice) a variation was produced in the earth's field around the cage at radio frequency, say at $\lambda = 1{,}700$ meters or $\omega = 10^6$

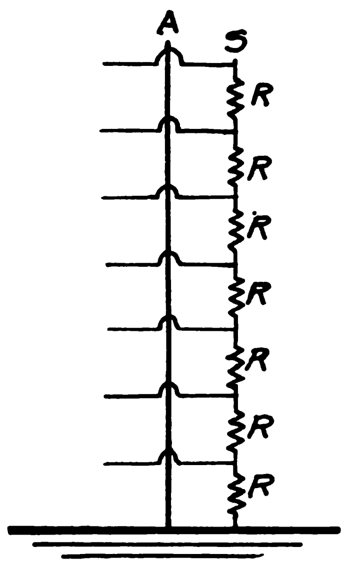


FIGURE 3—Dieckmann Shield. Side View

Suppose further that it corresponded to a potential difference between the top and the bottom of the grounding wires of 1 volt. Imagine further that the grounding wire resistance was 2,000 ohms and that of the antenna 10 ohms. We shall assume an antenna height of 30 meters (100 feet) and an average distance between the cage wires and the antenna of 30 cm. (1 foot). These strays will not affect the antenna directly, since their electrostatic field will merely cause currents to flow up and down the grounding wire without producing any electrostatic field variation within the cage, as indicated under (1) above.

We have taken the constants for this case as severely prejudicial to successful operation as could possibly be expected by bringing the grounding wire very near to the antenna itself.

Digitized by Google

We might expect, therefore, that the currents flowing up and down the grounding wire would magnetically induce similar currents in the antenna, thus permitting the excitation of the antenna by such variation of the earth's field.

A simple calculation will show, however, that the effect is negligible, even in this impossibly extreme case.

The mutual inductance between the two wires is 25 μh. If the 1 volt were applied to the antenna directly, since the antenna is resonant to the incoming frequency, we would have a current of 0.1 ampere flowing therein. In the grounding wire, also supposed resonant (tho aperiodically damped), there will actually flow 0.0005 ampere. This will induce in the neighboring antenna a current

$$i_2 = \frac{M\,\omega\,i_1}{R} = 0.00125 \text{ ampere.}$$

In other words, there is induced in the antenna approximately one one-hundredth the current and one ten-thousandth the energy which would be present were the antenna unshielded. Needless to say, in actual practice, this shielding effect would be vastly enhanced and the protection of the antenna by a Dieckmann cage of reasonably large dimensions would be practically perfect.

6. It remains then to explain the previous failure of experimenters in the radio field to eliminate strays. A brief consideration of Figure 4 and of Dr. de Groot's classification of strays clears up the question, as stated in the paper. Figure 4 shows the complete receiving system designed to eliminate strays. The two antennas A_1 and A_2 are each protected by a Dieckmann cage from strays of types 2 and 3, that is, those due to overhead rain clouds and cosmic bombardment of the Heaviside layer. Both these types of strays produce not periodic electromagnetic waves but extremely powerful increases in the potential gradient of the earth's field, but these are intermittent and unidirectional. As explained under (3) above, these disturbances will not reach the antennas. However, the strays of type 1, which are periodic electromagnetic waves originating in lightning storms, will pass thru. These will reach the antennas, but by means of the audio frequency compensation indicated, these periodic impulses can be balanced out leaving the signal still present.

It is important to remember that an essential feature of the system is to ground *aperiodically* all nearby conductors. Otherwise these will be set into vibration by variations in the earth's field and will radiate electromagnetic waves which will be of

Digitized by Google

small damping and will get to the receiving antennas. The neglect of this precaution by all previous experimenters immediately renders criticism of this method by them on the basis of their experiments quite valueless since neighboring ungrounded or periodically grounded conductors would quite upset the proper operation of the system.

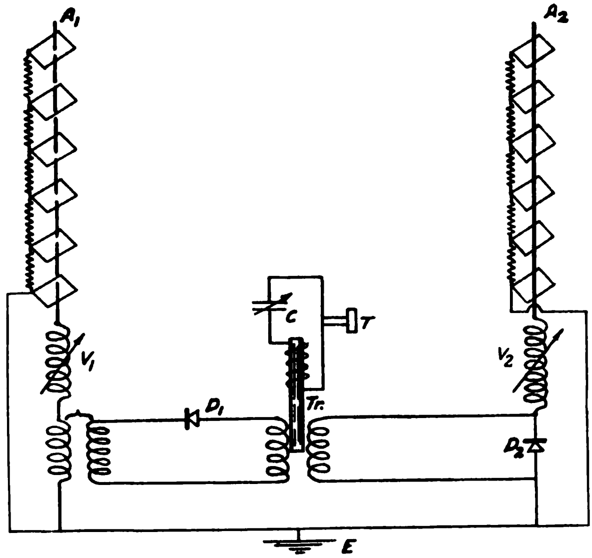


FIGURE 4—Complete de Groot Stray Eliminator, 1914

7. One further question should be considered. This is, why does one not use the audio frequency compensation method for all three types of strays instead of only for the periodic disturbances?

Light is thrown on this question by Figure 5. In the left hand side of the Figure, top curve, is shown an hypothetical sharp impulse lasting, say, 0.000,001 second (1 μs.). Its effect in the antenna A_2 which is aperiodic will last but little longer. On the other hand, its effect in the antenna A_1 will last for something like 150 μs. if the antenna A_1 is tuned to $\lambda = 1{,}000$ m. and has a decrement of $\delta = 0.1$. The magnetomotive force in the core of the differential transformer *Tr* will follow the curve labelled A_1—A_2 and will last 150 μs. It will therefore be responsible for a sharp click in the telephone receivers. No audio

Digitized by Google

frequency compensation is therefore to be expected. If, however, the stray is of $\lambda = 10{,}000$ m. and of $\delta = 1.0$ (and large energy), it will last for approximately 180 μs. Its effect in the antenna A_2 will last approximately as long. Its effect in antenna A_1 will be not markedly different from that in A_2, and the differential magnetomotive force curve will be as indicated in A_1—A_2.

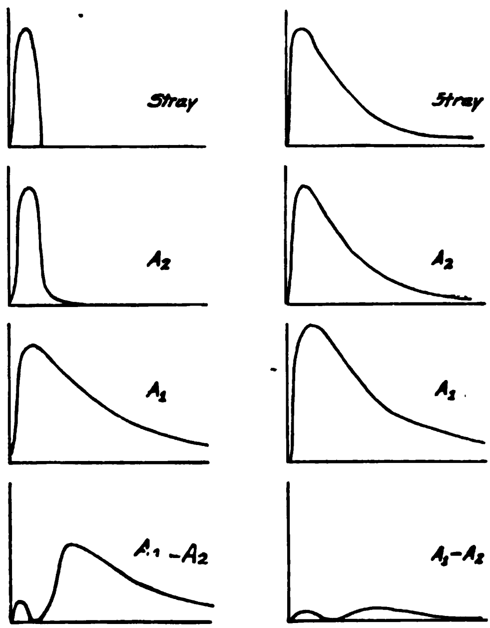


FIGURE 5—Envelope of Rectified Current

It will be noticed that the second magnetomotive force curve differs from the first in two respects: viz., that the maximum value is much less, and that the time rate of change thereof is much less. Consequently the resulting induced e.m.f. in the telephone circuit or secondary of the differential transformer will be extremely small in the second case as compared with that in the first.

It is probably some such considerations as these which have led Dr. de Groot to adopt audio frequency compensation only for reasonably periodic strays such as originate in lightning storms, and to eliminate sharp aperiodic strays by the shielding

Digitized by Google

method. It is indeed fortunate that the latter type of strays have been found by experiment to be of the sort shown to be eliminable under heading (3) above.

Roy A. Weagant: Referring to the Faraday cage which Dr. Goldsmith has shown and which he states will be extremely effective in keeping both strays and the signal out of the antenna, I would state that obviously this cage is a simple vertical antenna and when acted upon by electromagnetic waves due either to strays or signal would have oscillatory currents flowing up and down it. This structure would have strong electromagnetic coupling with the antenna inside it and currents would of necessity set up in the antenna, so that both signal and stray would affect it.

4. Replying to Dr. Goldsmith again, I do not think it would make any difference whether this cage were aperiodic due to the insertion of high resistance or were capable of oscillating freely. If currents flow in it they will induce oscillating currents in the antenna itself.

5. Another point which apparently has not been covered in the papers which Dr. Goldsmith has referred to is the absorption of energy by the cage from the oscillating energy in the antenna. Assuming that the antenna has oscillating currents flowing in it, by reason of its coupling to the cage, energy would be extracted by the cage and probably to a very large extent.

6. There is another point which I would like to bring up and which none of the various explanations offered cover and which does not seem to be taken account of in the suggested methods of eliminating strays, viz., the very great increase of stray intensity as the wave length to which the receiving antenna is tuned is increased. I should be greatly pleased if anyone present could offer any explanation of this fact.

7. Is there any information indicating whether or not there is any peak in that effect.

8. The last statement of Dr. Goldsmith checks up with my own experience. There is a point in connection with Mr. Armstrong's reference to the heterodyne receiving method which I should like to amplify a little. Mr. Armstrong was a little modest in the way in which he stated the case. The heterodyne alone is not of any particular value in working thru strays. The really valuable thing is that method of using the heterodyne system which is embodied in Mr. Armstrong's invention of the regenerative circuits for the oscillating valve. The character-

Digitized by Google

istic of a vacuum valve when in the oscillating condition is such that its response to strong impulses is greatly reduced while its ability to amplify weak impulses is greatly increased. The result of this is that a valve in the oscillating condition may not give any louder response to a stray impulse than an ordinary crystal, while its response to a weak signal may be hundreds or even thousands of times greater.

Alexander E. Reoch: (by letter): I am not in the position to make any comment on Dr. de Groot's theory of the origin of strays, but the work he has done in determining the actual nature of the strays as received at the radio station is undoubtedly valuable.

As far as my information goes, the best method available for the elimination up to the present time is that recently patented by G. M. Wright of London, England, wherein the three-element valve is used with limited current-carrying capacity between the filament and the plate. The effect is that strays are reduced to the same strength as the signals. The balanced detector system also reduces the strength of strays to the strength of the signals, but in this case by opposing the audio frequency currents, whereas in the new arrangement the currents retain the radio frequency form, and can be further manipulated for increase of strength or reduction of damping so as to allow of further selection of signals from strays.

In the method suggested by Dr. de Groot for the elimination of periodic or Type 1 strays several difficulties arise. If the antennas are to be efficient as receivers, the distance between them will have to be very considerable or they will interact on one another, and the design of two antennas of the same size and wave length with different receptive properties as regards signals and both equally receptive to strays is by no means a simple matter. Assuming that in Figure 4, antenna 2 receives no energy from the signals (in which case there will be no opposing audio frequency current), half the energy which would ordinarily be available for the operation of the telephone from detector 1 will pass by means of the audio frequency transformer thru detector 2. This is a loss that has previously been encountered in efforts carried out along these lines to eliminate strays. It is quite serious, and unless special means are devised to prevent it, forms an objection of no small importance to this method.

The use of the Dieckmann cage seems to offer good promise, involving, however, some constructional difficulties.

Digitized by Google

The whole subject is one of extreme interest, and the difficulties encountered are by no means small. There seems to be little doubt that the nature of the strays will vary in different latitudes and with different climates. Whether their classification into Dr. de Groot's groups is possible at all parts of the world remains to be proved; and it seems more than likely that each locality will have its own peculiar type of strays requiring special treatment in each case.

Walter S. Lemmon: As regards the production of strays of the third class, by cosmic bombardment, would not the Heaviside layer shield the earth from such a disturbance, inasmuch as the Heaviside layer is a conducting surface completely surrounding the earth?

Alfred N. Goldsmith: We may assume that the actual burning up of the meteorites and the consequent production of strays takes place only when the meteor reaches denser (and therefore less conducting) layers of air than those in the Heaviside layer.

Digitized by Google

ADDITIONAL EXPERIMENTS WITH IMPULSE EXCITATION * †

By

Ellery W. Stone

(Assistant Radio Inspector, United States Department of Commerce)

In the June, 1916 issue of the Proceedings, the writer published a paper dealing with the design and operation of an impulse excitation transmitter. It is the purpose of this paper to set forth the results of some further experiments with this type of apparatus.

In the original paper, a hydrogen atmosphere gap of the modified Eastham-Peukert type, worked at considerably above atmospheric pressure, was described; and the various effects of gap speed, gap surface, and tone and antenna circuit absorption were set forth. In this paper, as in the last one, the term "impulse excitation" will be used to designate that form of shock excitation in which the antenna circuit is set into oscillation by a blow delivered from a rush of current in an adjacent aperiodic, or practically aperiodic, circuit as distinguished from the "beat" excitation of those quenched gap transmitters which make use of several current oscillations in the gap circuit before the antenna circuit is excited to free oscillation.

The writer has found it of assistance in the contemplation of impulse excitation to consider shock excitation in general to be divided into two regions of action, the one—impulse excitation, the other—"beat" excitation, using the definitions of these two terms given in the preceding paragraph. A transmitter which ordinarily might come in the one class, may, by the mere alteration of its spark gap, be placed in the other. That is to say, a gap circuit of high capacitance and low inductance, the action of which ordinarily places it in the "beat" excitation region, may be placed in the impulse region by the employment of one or more of a variety of artifices, and the reverse action may take place by the omission of the same.

* Received by the Editor, September 1, 1916.

† See "Proceedings of The Institute of Radio Engineers," volume 4, number 3, page 233.

Digitized by Google

For instance, in the original paper, it was shown that when using the rotary quenched gap, with sectored surfaces, in air, impulse excitation could not be obtained. However, by the use of alcohol vapor at a pressure above atmospheric, this gap action could be brought well within the impulse region. The use of smooth gap surfaces brought it still further within this region and the use of a tone circuit shunted across the gap acted even more favorably. While the omission of any one of these aids to rapid damping of the current in the impulse circuit will still keep the action of the gap well within the impulse region, the use of all of them is desired.

Hydrogen Field

With reference to the employment of the hydrogen atmosphere under pressure in the transmitter described in the original paper, the criticism has been made that too much time would elapse before the proper pressure could be built up, but this may be easily answered. In the first place, the use of the alcohol vapor is not essential to bring the gap action into the impulse region if smooth disks are used in the gap or if the tone circuit is used with either set of disks. But even when the sectored disks are used without the tone circuit, the pressure is built up within the gap just as rapidly as it is needed. Conductivity of the gaseous medium between the electrodes of any gap "is due mainly to the ions of the metallic vapor formed by the heating of the electrodes."[1] So long as the gap electrodes remain cool, and hence the surrounding medium, a high resistance, and therefore good quenching, will be maintained. Thus, at the start, when the gap is cold, the alcohol vapor under pressure is not needed to secure a high resistance. However, as soon as the enclosed gases begin to heat, the very heat which ordinarily would lower the resistance of the gap causes the increased pressure of the alcohol vapor, which raises the resistance.

That "the one action automatically compensates for the other," as stated in the original paper, has been repeatedly demonstrated. Using the sectored disks, the gap has been operated without the hydrogen vapor, causing the initial antenna current to drop rapidly 45 per cent. and more. The current drop is due to the fact that as the enclosed air heats, impulse excitation no longer takes place and the transmitter becomes merely a

[1] From "Wireless Telegraphy," Zenneck-Seelig, page 98.

Digitized by Google

"beat" excitation, quenched spark transmitter, the gap and antenna circuits of which have widely different time periods. Upon admitting alcohol to the spark chamber, vaporization immediately takes place and sufficient pressure is made to cause the antenna current to return instantly to its normal value, indicating that impulse excitation is once more taking place.

Coupling

The criticism was also made that the coupling between the impulse and antenna circuits in the transmitter previously described was not sufficiently close. Figure 5 of the original paper is herein reproduced as Figure 1. This illustration shows the

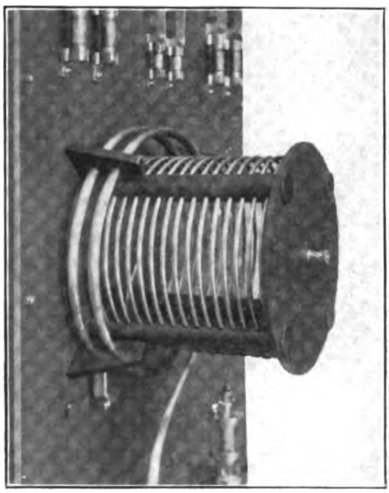


FIGURE 1

inductive coupler. While the coupling between the two windings is close when considering the usual coupled circuits, it is in reality fairly loose for impulse operation, and the writer is grateful for this fact being called to his attention.

There are two methods by which the coupling between two circuits may be increased, one—purely mechanical, the other—electrical. The first is to increase the proximity of the two windings of the inductive coupler, the other is to make, as nearly as possible, all of the inductance in each circuit common to both. The latter limit would result in maximum coupling, but it is of

Digitized by Google

course impossible to attain. The nearest approximation is to combine the usual antenna loading inductance with the antenna circuit winding of the inductive coupler, thus bringing all of the lumped inductance of the antenna circuit into the field of the impulse circuit. In addition, as much of the inductance in the impulse circuit as practicable should be designed so as to be effective in inducing energy in the antenna circuit winding of the coupler.

A reference to Figure 2, which shows the new coupler, will show how these two methods have been utilized. The impulse circuit winding of the coupler has been reduced to but one turn,

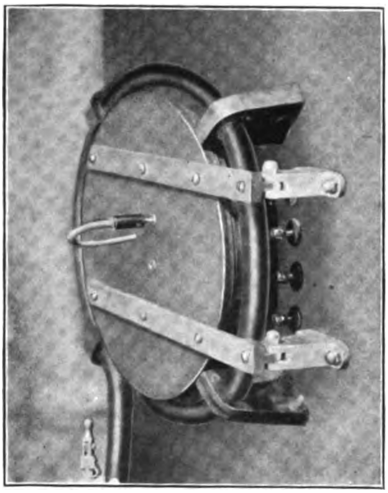


FIGURE 2

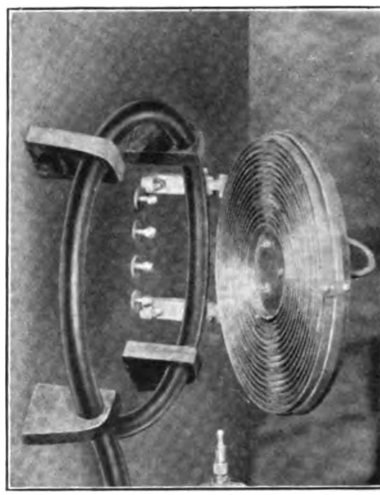


FIGURE 3

and the condenser capacitance increased. In order to handle the momentarily high current amplitude, a special form of litzendraht has been made up, which is enclosed in a vulcanite tube for protection. The antenna circuit winding is wound spiral fashion on an insulating base and is arranged to swing directly into the single loop of the impulse circuit inductance.

Figure 3 shows the antenna circuit winding swung back from its normal position in order to show the construction.

Due to the low potentials generated in the antenna circuit, the turns of the antenna circuit winding may be very closely spaced, thus securing enough inductance to obviate the necessity of loading inductance.

Digitized by Google

A plug with two sockets is shown, one for 600 meters, the other for 300 meters. The connections are such as to cut in a series condenser in the antenna circuit when the plug is inserted in the 300 meter socket.

The adoption of the new coupler resulted in a two-fold advantage, i. e., increased antenna current together with a lower antenna current decrement.

Figure 4 shows three resonance curves for various wave length settings of the antenna circuit with a fixed time period of the impulse circuit. Expressing this time period in terms of wave length, this was about 700 meters.

Gap Length

The effect of gap length is of more than slight importance in the attainment of impulse excitation. Figures 5, 6, 7, 8 and 9 show resonance curves of the current in the antenna circuit for various gap separations, using the smooth disks. It should be borne in mind that, because of the construction of this particular type of gap, the actual spark length is twice the gap separation. The stationary disk is divided into two parts to which the terminals from the secondary of the step-up transformer are connected. The spark passes from one stationary electrode to the revolving disk and back from the disk to the other stationary electrode, thus making the total spark length twice the separation distance.

In each of these resonance curves, the logarithmic decrement given is the antenna current decrement; that is to say, the decrement as computed from the resonance curve minus the decrement of the measuring instrument.

From the curves, it will be seen that the best results are obtained when the gap length is as short as it is possible to make it. In actual practice, the revolving electrode is screwed up to the stationary one by means of the bearing shaft, which is threaded into the casing of the spark chamber, until the two touch. The bearing is then turned backward just enough to separate them from contact.

This is illustrative of one advantage of the revolving impulse discharger over the stationary one. To preserve such an exceedingly short distance with a stationary gap is somewhat difficult. The theory of the plane surface, short gap is that by providing large parallel surfaces, "wandering" of the spark may be effected, since as fast as the electrode is pitted, thus increasing

Digitized by Google

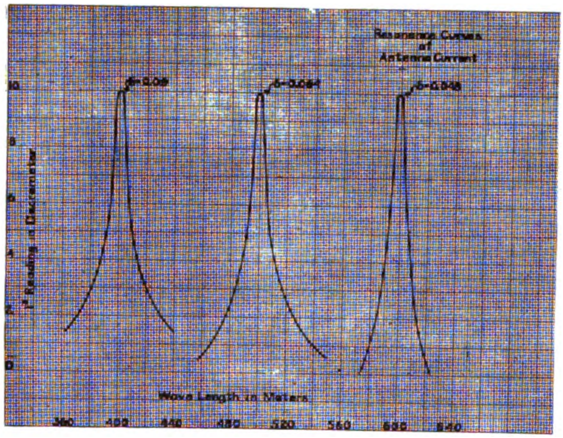


Figure 4

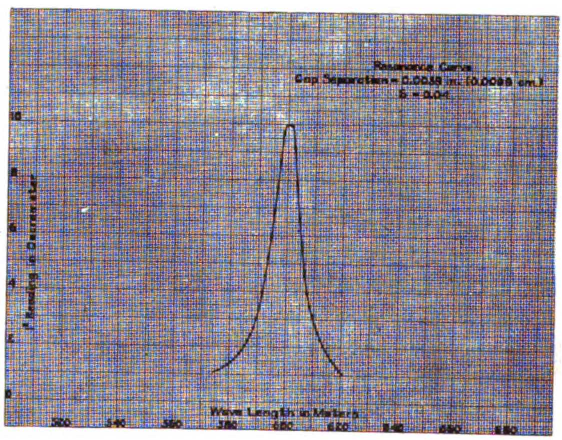


Figure 5

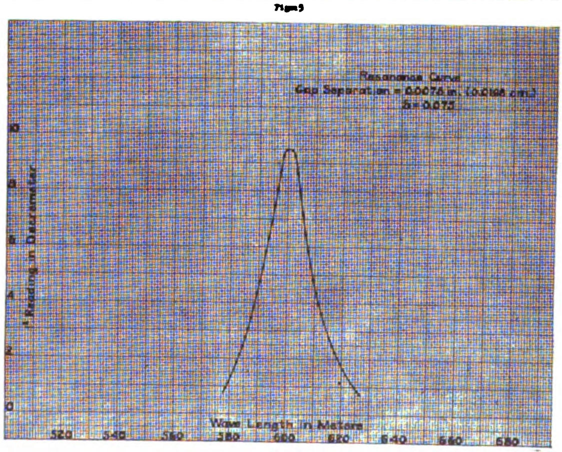


Figure 6

Digitized by Google

the gap length, the spark moves to a new and cooler position. This may work quite satisfactorily in ordinary quenched gap operation where the current amplitude in the gap circuit is not extremely high, but with impulse excitation and the consequent momentarily high current value encountered, burrs are very often formed on the gap surface. This prevents spark "wandering," and the action being cumulative, the gap soon becomes short-circuited.

With a revolving discharger, on the other hand, such effective "wandering" of the spark is obtained as to eliminate the formation of burrs and extremely low gap lengths may be employed without danger of fusion.

However, the use of a revolving discharger with a separation of the order of 0.004 inches (0.01 centimeter) necessarily entails extremely accurate lathe work. Roller bearings at each end of the bearing shaft and a system of facing up all surfaces have made the realization of such a short gap possible.

As set forth in the original paper, one of the chief requisites for high damping of the current in the impulse circuit is that the gap must rapidly regain its initial high resistance. That is to say, de-ionization of the gases between the gap electrodes must be effected as speedily as possible.

Zenneck discusses the various factors tending to bring about the de-ionization of spark gaps,[2] and concludes that such de-ionization is caused chiefly by the electric field between the gap surfaces and by absorption of the ions by the electrodes. It will be seen that the shorter the gap length, the more intense the electric field, and the more opportunities for absorption of ions by the gap disks.

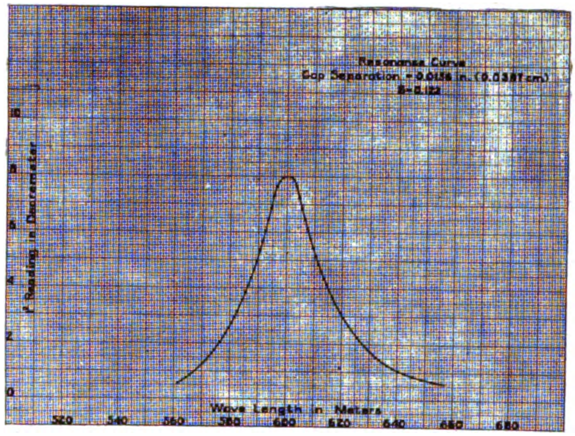
The fact that a very short gap insures more rapid damping of the current in the impulse circuit than a longer one explains why better results were obtained with smooth instead of sectored gap disks as set forth in the original paper. The sectored gap, having projecting surfaces as in any rotary gap, causes the spark discharge to be drawn out, or the electrodes separated, as the projections pass each other, which is equivalent to using a gap of wider separation.

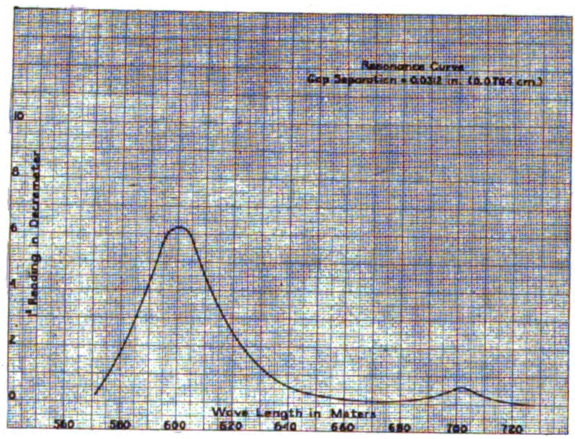
In taking the data for the curves in Figures 5, 6, 7, 8, and 9, the tone circuit was omitted for fear of puncturing the paper condenser in that circuit, due to raising the potential across the gap by the abnormal separation of the disks.

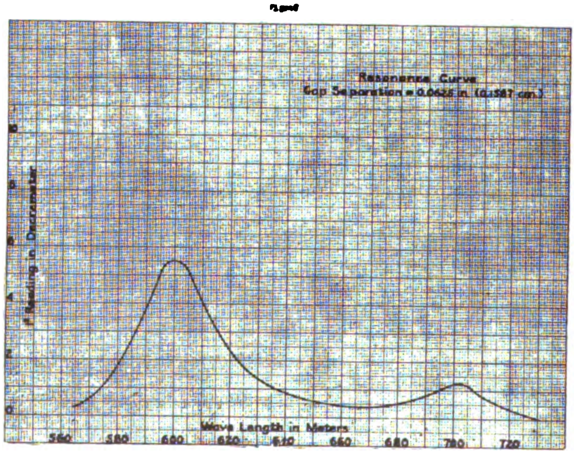
Figure 10 shows a curve of antenna current for the various

[2] "Wireless Telegraphy," Zenneck-Seelig, page 97, *et seq.*

Digitized by Google







Digitized by Google

gap separations used in the preceding curves. It will be noted that while this current curve is a rising one with increased gap separation, the resonance curves in Figures 5, 6, 7, 8 and 9 successively decrease in amplitude. This is an excellent demonstration of the unreliability of aerial ammeter readings in damped wave transmission, at least, so far as the determination of effective energy for signalling purposes is concerned. Contrary to

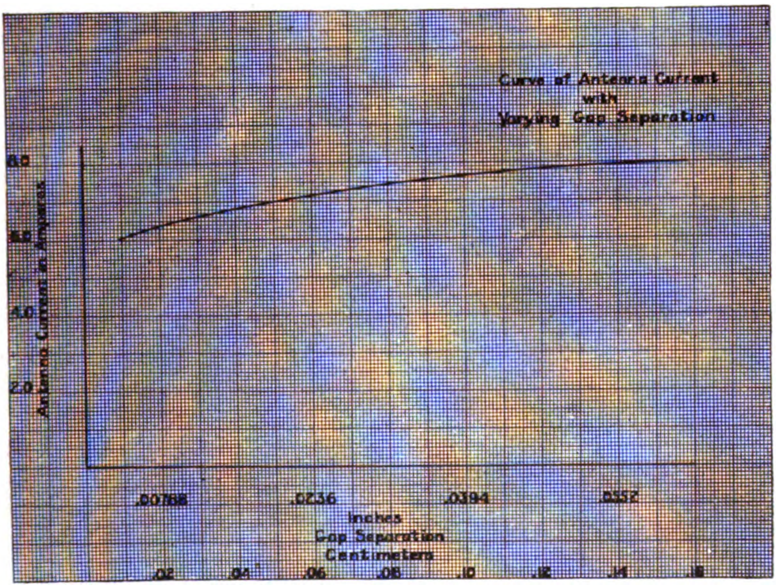


Figure 10

the action of the current indicating device in a decremeter, the aerial ammeter indicates the average integral effect of a large number of oscillations instead of the current amplitude at the oscillation frequency of the antenna circuit. Other things being equal, the higher the decrement of the antenna current, the greater the aerial ammeter reading—hardly a reliable method of measurement.[3]

Tone Circuit

Figure 11 shows the schematic diagram of connections, the tone circuit being shunted across the impulse discharger. The condenser in the tone circuit is a paper one with fairly high

[3] Cf. Discussion by J. Zenneck, "Proceedings of The Institute of Radio Engineers," volume 4, number 4, page 337.

Digitized by Google

capacitance. With this particular transmitter, signals are louder when received on crystal or audion (non-oscillating) detector when the tone circuit is used. However, because of the irregular impulse frequency and possible train interference in the antenna circuit, the note is not musical, altho possessing definite pitch. Mr. Eldridge Buckingham has found from experimentation with a Cutting and Washington gap on alternating current that, when using the tone circuit, the purest notes are obtained when the frequency of the tone circuit is some multiple of the supply frequency, or the group impulse frequency. This is in confirmation of one of the experiments described in the original paper in which the action of the tone circuit was noted when shunted

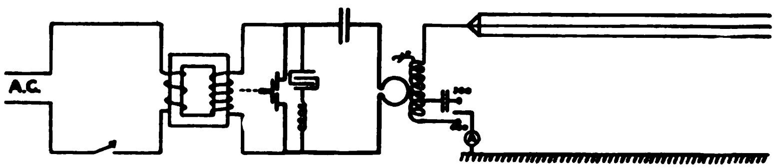


FIGURE 11

across the sectored gap. "Certain speeds of the gap were found which tended to improve the tones greatly . . . . (These critical gap speeds were probably those which placed the impulse group frequency in resonance with the oscillation frequency, or a multiple thereof, of the tone circuit.)"

The use of a higher supply frequency would not tend greatly to improve the situation since it would not insure any more regularity of the impulse discharges. However, with a tone circuit adjusted to the same audio frequency as that of the supply current, say 500 cycles, favorable results should be obtained. Such an arrangement might seem unnecessary if it were not for the fact that the addition of the tone circuit secures greater telephonic response, altho with no actual increase of received energy, at the receiving end.

This is because, when omitting the tone circuit, the great number of partial discharges or impulses and their irregular spacing "tend to weaken rather than strengthen the effect upon the telephone diafram, as it may often not have time to return to its position of equilibrium and in any case is forced into extremely complex movements."[4] This is evidenced by the very

[4] "Wireless Telegraphy," Zenneck-Seelig, page 198.

Digitized by Google

definite click heard in the receivers when the transmitter key is depressed and again when it is released.

This same lack of auditory response with crystal detector is encountered in arc operation. Here, the frequency is so high as to prevent the diafram from vibrating in its normal fashion, and it is simply pulled over toward the magnets and held there until the current flow ceases.

With the alternating current impulse excitation transmitter, the addition of the tone circuit, by the superimposition of its regular, audio frequency oscillations on the hissing impulse note, secures a more pronounced auditory effect.

The use of a sectored gap, properly milled, connected synchronously to the shaft of a 500 cycle generator, and with the voltage so adjusted as to give but one impulse per half cycle, has been suggested. This would undoubtedly produce a clear note without the use of a tone circuit. Whether the energy transfer between the impulse and antenna circuits would be as efficient with such a low impulse frequency might be questioned.

SUMMARY: After drawing a definite distinction between "impulse excitation" and "beat excitation," the writer considers broadly the conditions under which each of these is brought about.

In connection with a type of impulse excitation transmitter, there are considered the effect of a hydrogen atmosphere in the gap, the construction of the necessarily closely inductive coupler between spark gap circuit and antenna circuit, the effect of gap separation and "wandering" of the spark, and the effect of the tone circuit shunted around the gap.

BIBLIOGRAPHY

Chaffee, E. Leon, "Impact Excitation of Electric Oscillations," "Proceedings of the American Academy of Arts and Sciences," volume XLVII, number 8, Nov., 1911.

Eastham, Melville, "The 'Hytone' Radio Telegraph Transmitter," "Proceedings of The Institute of Radio Engineers," volume II, number 4.

Eccles, W. H., "Handbook of Wireless Telegraphy and Telephony," page 85 *et seq.*, page 187, page 190, page 355, page 404.

Espinosas De Los Monteros A., "Jahrbuch der drahtlosen Telegraphie," volume I, page 480, 1908.

Glatzel, B., "Physikalische Zeitschrift," volume II, page 893, 1910.

"Jahrbuch der drahtlosen Telegraphie," volume IV, page 400, 1911.

Peukert, W., "Jahrbuch der drahtlosen Telegraphie," volume III, page 199, 1909.

Digitized by Google

PIERCE, G. W., "Principles of Wireless Telegraphy," page 250, page 265, *et seq.*

REIN, HANS, "Jahrbuch der drahtlosen Telegraphie," volume IV, page 196, 1911.

"The Multitone System," "PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS," volume I, number 4.

STONE, ELLERY W., "An Impulse Excitation Transmitter," "PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS," volume IV, number 3.

WASHINGTON, BOWDEN, "Some Small Direct Current Sets," "PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS," volume IV, number 4.

WASMUS, A., "London Electrician," volume 64, page 550, 1910.

WIEN, MAX, "Physikalische Zeitschrift," volume VII, page 871, 1906.

ZENNECK, J., "Wireless Telegraphy," (Trans. by Seelig) page 95 *et. seq.*, page 122, page 148, page 182 *et seq.*, page 192, page 198, page 229, *et seq.*

Digitized by Google

A STUDY OF HETERODYNE AMPLIFICATION BY THE ELECTRON RELAY*

By

Edwin H. Armstrong

(Trowbridge Fellow, Hartley Research Laboratory, Department of Electro-Mechanics, Columbia University.)

Part I

The purpose of this paper is to present the results of an experimental investigation of the heterodyne phenomena which occur in the oscillating state of the regenerative electron relay. The questions to be determined were first, the magnitude of the amplification produced by the presence of the local or auxiliary current, and second, the nature of this amplification and the factors which limit its extent.

In self-heterodyne circuits of the regenerative type there are, as the names indicate, two methods of amplification, and these occur simultaneously in the same circuit, each one operating in its own particular way and practically independently of the presence of the other to produce a total amplification proportional to the product of the two. On account of the rather involved nature of the various phenomena, the problem of separating the total amplification into its component parts by direct measurement is not simple and an indirect method is the easiest way out of the difficulty. In the light of our present knowledge concerning self-heterodyne circuits, there is no reason to believe that the magnitude of the heterodyne amplification obtained in these circuits should in any way differ from that obtained in an ordinary circuit with an external heterodyne. Hence by measuring the amplification produced in a simple audion circuit and then by measuring the total amplification produced when the same tube is provided with a regenerative circuit and used as a self-heterodyne, a general idea of the actual and relative magnifications of the two methods may be obtained.

This method of measurement was therefore adopted and the

* Presented before The Institute of Radio Engineers, New York, October 4, 1916.

Digitized by Google

arrangement of apparatus was made according to the diagram of Figure 1. Referring now to this diagram, *M* represents the antenna circuit and *N* the closed circuit of an electron relay receiver which may be made regenerative by the opening of the switch *S*. The electron relay, which was of the audion type, was used as the detector and a condenser C_1 was included in the grid circuit in the ordinary way. On account of the high vacuum

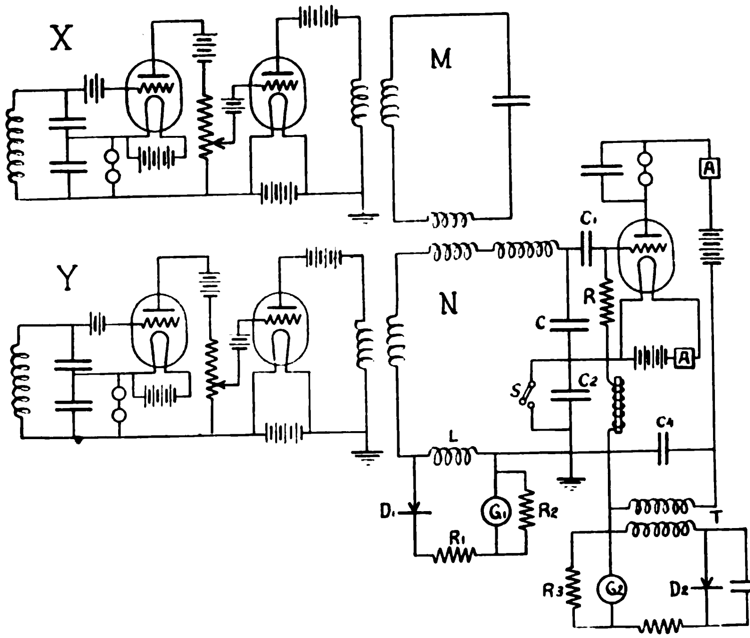


FIGURE 1

of the tube an auxiliary leak was required and a high resistance *R* was used between the grid and the negative terminal of the filament. The two systems *X* and *Y* represent the sources of signaling and local currents respectively. Each system consists of an oscillating electron relay arranged to excite a second relay, the input side of which was connected across a resistance located in the plate circuit of the oscillator. Energy is supplied to the receiver from the plate circuit of the second tube which acts purely as a repeater. This arrangement was adopted in order to prevent the amplification of the signaling current in circuit *N* by the regenerative action of the circuits of system *Y* which would occur with a direct coupling between the two. By using

Digitized by Google

a one way repeater with the input side connected across a resistance in the plate circuit of the oscillator, this danger is avoided. The same arrangement was adopted in system X to prevent the relatively strong local current reacting in any way on the source of the signaling current. The relative amplitudes of the signaling and local radio frequency currents in the closed circuit were measured by means of a silicon rectifier D_1 and a galvanometer G_1. The combination was connected across a small inductance L one end of which was grounded. A shunt resistance R_2 across the galvanometer was used to vary its sensitiveness and a series resistance R_1 was used to compensate for changes in the total resistance due to adjustment of the shunt. The telephone current was measured in the manner described by Dr. Louis Austin* in a recent publication. A telephone transformer T separates the variable components of the plate current from its continuous component and a silicon rectifier D_2 and a galvanometer G_2 located in the secondary are therefore responsive only to changes in the plate current. To separate the audio from the radio frequencies, condensers C_4 and C_5 of 0.01 μf. each were connected across both the primary of the transformer and across the rectifier and as an additional precaution one end of the secondary of the transformer was grounded.

Both the silicon rectifier used for the measurement of the radio frequency and the silicon-arsenic rectifier which was used for the measurement of the audio frequency follow the square law in the lower part of their characteristics; that is, the rectified current is proportional to the square of the alternating current. The reading of the galvanometer G_1 is therefore proportional to the square of the radio frequency current in the circuit N. The reading of the galvanometer G_2 is proportional to the square of the audio frequency component of current in the plate circuit. The alternating current energy available for producing sound is likewise proportional to the square of the current and the reading of the galvanometer G_2 may therefore be taken as a direct measure of telephone signal strength.

In determining the amplification due to the heterodyne method a difficulty is encountered in continuous wave reception due to the fact that when the local current is not present there is no audible signal in the telephones. In order to obtain a tone a chopper must be used in some part of the receiving system. In the present investigation a chopper of the revolving commutator type was used in the antenna circuit and the square

* In the "Proceedings of the Washington Academy of Sciences."

Digitized by Google

of the variable component of the telephone current taken as a standard of reference on which to base the relative strength of signal produced by the heterodyne.

The first series of measurements were for the purpose of comparing the signal strength obtained with a chopper and that given by the heterodyne when the local current was equal in amplitude to the signaling current. For convenience we may refer to this case as the "equal heterodyne," i. e., "equal other force." The conditions under which the comparison was made were the following: The signaling frequency was set at about 40,000 cycles and the frequency of the local current adjusted to a given beat tone approximately equal to the maximum frequency of interruption produced by the chopper. This was about 600 cycles per second. After a rough adjustment of the tuning and coupling of circuits M and N, the grid condenser C_2 and the auxiliary leak R were adjusted to give maximum response in the telephone. The values of capacity and resistance which gave this result were 0.0001 μf. and 2 megohms respectively. The time constant of the discharge of the grid condenser thru the leak is therefore about 0.0002 seconds. After this adjustment was completed, the local current was cut off and circuits M and N carefully adjusted until a maximum of current was obtained in circuit N as indicated by the maximum deflection of galvanometer G_1. These adjustments were held constant thruout all measurements in which the external heterodyne was used. The comparison was made over a wide range of signal strength and it was found that the equal heterodyne gave a signal which was from four to ten times as loud as that given by the chopper, the greatest advantage being on the weaker signals. The four fold amplification usually attributed to the equal heterodyne with respect to the chopper is fully realized but the ten-fold amplification was rather unexpected. The explanation is, however, a simple one, and will appear in the second part of the paper.

The second series of measurements were for the purpose of comparing the signal strength of the equal heterodyne and that obtained when the local current is increased to its critical value. This case may be referred to as the "optimum heterodyne." The results of these measurements are illustrated by the curve of Figure 2 which shows the relation between the amplification produced by the optimum heterodyne with respect to the equal heterodyne and the amplitude of the radio frequency signaling current. It is evident that the magnification varies over a very

Digitized by Google

wide range and depends on some inverse power of the signaling current. On the strongest signals the response for the best adjustment of local current was only about one and a half times as great as that of the equal current; whereas, on the weakest signal, the response was increased fifty-five times and the shape of the curve indicated that this would be greatly bettered for still weaker signals. An amplification of several hundred ap-

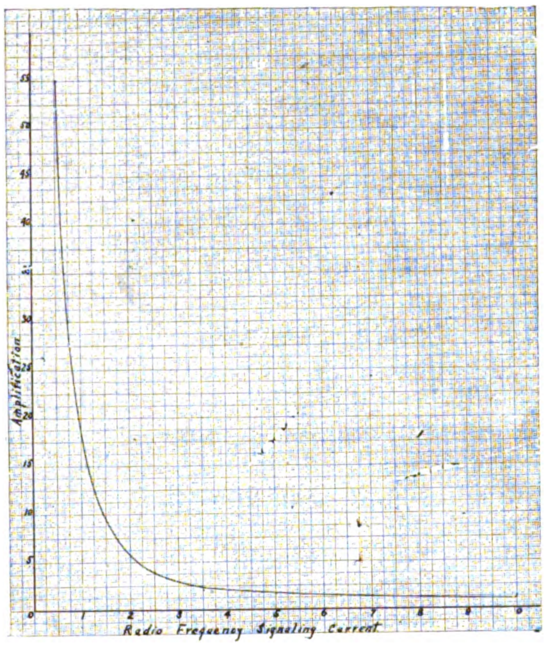


Figure 2

pears quite probable. With the apparatus on hand, it was impossible to measure accurately a signal weaker than that on which the fifty-five fold amplification was obtained. The missing part of the curve presents an interesting field for further investigation with more sensitive measuring instruments. An idea of the strength of signal may be gathered from the fact that a shunted telephone test gave an audibility of about one hundred for the weakest signal on the curve. This measurement was made for the equal heterodyne and it is important to note that the method employed was to insert a second pair of telephones in series with the shunted pair and to take the square of

Digitized by Google

the expression $\frac{Z_T+R_s}{R_s}$ as the audibility. The justification of this procedure will be found in a contribution of L. Israel* which fully covers the present case.

The next series of measurements were for the purpose of determining the relation between the maximum signal strength obtainable with a simple electron relay with separate heterodyne and the signal obtainable when the same relay is supplied with a regenerative circuit and operated as a self-heterodyne. A large number of comparisons were made on a frequency of about 40,000 cycles. The results were extremely irregular due to the very critical nature of the adjustment of the self-heterodyne circuit but there was found to be an average amplification of about fifty times with respect to the signals produced by the external heterodyne. The delicacy of the adjustment may be gathered from the fact that even tho the tuning condenser of circuit N was provided with a handle a foot in length the slightest touch would frequently produce a change of 100 per cent. in the deflection of the galvanometer G_2. In addition to the arrangement of Figure 1, other forms of regenerative circuits were used, including the magnetic coupling and the particular form of static coupling illustrated in Figure 3 which has been termed in some quarters the "ultraudion connection." In spite of the claims by the patentee that it cannot be a regenerative circuit, and his explanation of the method of operation (which, by the way, involves perpetual motion),* this arrangement regenerates very effectively with a good bulb, and gives an amplification about fifty times greater than the simple connection with external heterodyne.

In summing up the total amplification obtained in the regenerative oscillating relay as compared to the signal obtained with the same relay in a simple circuit with a chopper, we find, taking average values, a multiplication of about five times by the equal heterodyne; a further magnification of at least twenty times by the optimum heterodyne, and lastly a fifty fold magnification by the operation of the regenerative circuit making a total of approximately 5,000. This figure has been checked by direct measurement and on weak signals even greater amplifications have been obtained.

---

* "PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS," volume 3, 1915, page 183. It should be noted, however, that as a high vacuum tube was used, changes in the resistance of the plate potential by adjustment of the shunt will not affect its sensitiveness. The sole object of the extra pair of telephones was to maintain constant the impedance of the plate circuit for the audio frequency current.

Digitized by Google

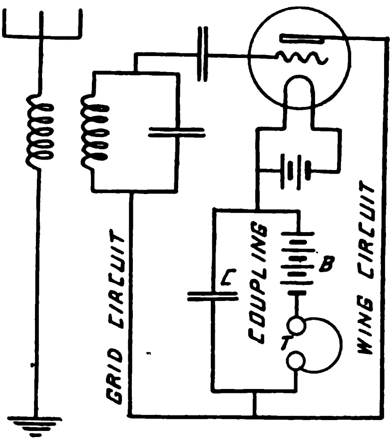


FIGURE 3

PART II.

THE NATURE OF THE HETERODYNE PHENOMENA

Several writers have treated the heterodyne phenomena mathematically,* but on account of various difficulties which arise, none of the treatments have been rigorous. When the special case of the current rectifier type has been considered it has been largely on a basis of physical reasoning. Without entering into details of the operations employed in getting at results, we may consider the conclusions arrived at by the various writers. They may be divided into two general classes, one of which supports the view that the amplification which may be obtained is, theoretically, unlimited, the practical limit being determined by the disturbances produced in the receiving system by the local frequency and the current carrying capacity of the detector. The second theory, which is that due to

* PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS," volume 4, 1916, page 266. Discussion on paper by Dr. L. W. Austin entitled "Experiments at U. S. Naval Radio Station, Darien." de Forest states "the circuit cannot be regenerative," and that the manner of operation is such that "a sudden change of potential impressed on the plate produces in turn a change in the potential impressed on the grid of such a character as to produce, in its turn, an opposite change of value of potential on the plate, etc. Thus the to-and-fro action is reciprocal and self-sustaining, etc." And all this self-sustaining to-and-fro action between grid and plate goes on (according to de Forest) *without any energy being supplied to the system!*
Also Hogan, "Proc. I. R. E.," July, 1913.
Cohen, "Proc. I. R. E.," July, 1913; June, 1915.
Liebowitz, "Proc. I. R. E.," June, 1915.
Latour, "Elect. World," April 24, 1915.

Digitized by Google

Liebowitz, states that the maximum true amplification due to the heterodyne is four; that this is obtained when the local current is equal in amplitude to the signaling current, and that any further increase in response which may be obtained by an increase in the local current is due to an improvement in the efficiency of the receiving apparatus and is governed by the usual limit in such cases, namely 100 per cent.

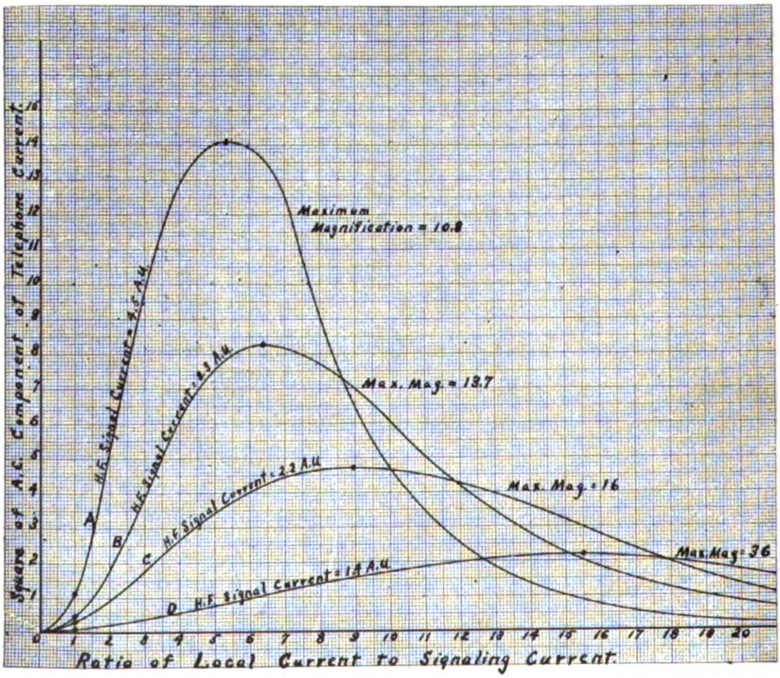


FIGURE 4

From an experimental standpoint, the key to the true nature of the phenomena would appear to lie in what may be termed the "heterodyne characteristic"; that is, the relation between telephone signal strength and the ratio of local to signaling current. A number of these characteristics for various values of signaling current were therefore obtained and the results are shown graphically in Figure 4. The ordinates of these curves represent the available energy in the telephones for producing a tone and the abscissa are in terms of the ratio of local to signaling current. It will be observed for all four values of signaling current that an increase in the ratio of the local to the signal-

Digitized by Google

ing current beyond the one-to-one point produces a very rapid increase in telephone signal strength which continues up to a certain maximum value. The maximum is maintained for a limited range and then the curves fall off and gradually approach zero value. This is the typical heterodyne characteristic for the current rectifier and the explanation of the phenomena attending the rise and fall of these curves should definitely determine the nature of the amplification.

The rapid rise in the curve as the local current is increased beyond the one-to-one point will be found in the shape of the rectifying or valve characteristic of the relay. In relays of the audion type, this characteristic is the relation between the gird voltage with respect to the filament and the grid-to-filament current. The curve of Figure 5 shows this relation for the relay which was used in obtaining the curves of Figure 4. The grid

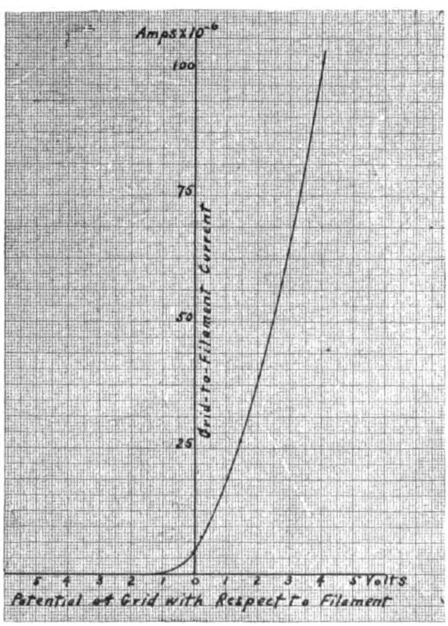


FIGURE 5

current is the actual conduction current flowing between grid and filament, and it is on the amplitude of this current that the value of the cumulative charge in the grid condenser depends. The curve may be divided into two parts, the upper section of which is practically a straight line and the lower section of which

Digitized by Google

is curved in such a manner that the ordinate is proportional, approximately, to the square of the abscissa. On account of this curvature, a difference exists between the conditions of operation of the equal and optimum heterodyne. A graphical representation of these conditions is given by Figure 6. In case (*A*), which shows the equal heterodyne a local voltage of amplitude *V* is continuously applied and maintains a continuous

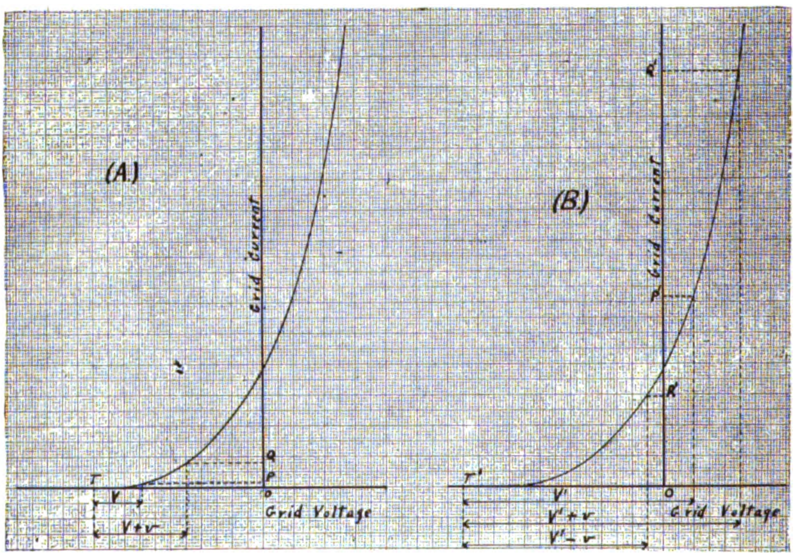


FIGURE 6

negative charge on the grid of some potential *T*. The value of the steady charging current is proportional to *O P*. When the signaling voltage *v* is superposed, we get, for the additive state a total voltage of $(V+v)$ and the charging current becomes proportional to *OQ*. For the opposing state the voltage $(V-v)$ is equal to zero and the charging current is consequently equal to zero. The total variation of the grid condenser charging current, and hence the variation in the average value in the average value of the grid potential, is between *O Q* and zero. The conditions of the optimum heterodyne are those illustrated by (*B*). A local E. M. F. of amplitude V' many times greater than the signaling voltage *v* continuously maintains the average value of the grid potential at some negative value T'. The steady value of charging current corresponding to V' is proportional

Digitized by Google

to $O' P'$. When the signaling E. M. F. is superposed for the voltage (V^1+v) the charging current is given by $O' Q'$ and for $(V'-v)$ by $O' R'$. The total variation in charging current is therefore proportional to $(O' Q'-O' R')$ or to $R' Q'$ which is obviously very much greater than the variation $O Q$ in the charging current for the equal heterodyne.

It must be here stated that the foregoing analysis must not be taken too literally as to quantitative results. Tendencies only are represented and these are limited by certain factors which will now be taken into account. The most obvious limit to an ever-increasing amplification by increase of the local current even if the valve characteristic followed the square law thruout is the counter E. M. F. of the grid condenser. The variation of the average value of the potential difference across this condenser can clearly never exceed the variation in amplitude of the beat voltage across the tuning condenser to which the relay is connected. When the efficiency of rectification is poor, as it is on the lower part of the characteristic, the counter E. M. F. of the grid condenser is negligible in comparison with the resistance reaction of the value. As the efficiency of rectification is improved by means of the local frequency, the back E. M. F. of the condenser becomes the dominating reaction of the circuit and definitely limits the variation of the charging current. The phenomena are almost identical with the action of the electrostatic telephone and coincides exactly with the theory of Liebowitz. In the case of the electrostatic telephone, the increase in the efficiency as the local current is increased produces a greater amplitude of vibration of the diafram. This in turn produces an increase in the counter E. M. F. of the telephone which reduces the amplitude of the signaling current and consequently the variation in amplitude of the beat current. In the vacuum valve, the same increase in efficiency is obtained until the resulting increase in the counter E. M. F. of the part of the apparatus on which the work is being done (in this case, the grid condenser), definitely limits further amplification.

The fall of the curves of Figure 4 are apparently due to the overloading of the tube by the local current. The steady value of the grid condenser charge maintained by the local current gradually cuts down the plate current as the ratio of local to signaling current increases. This interferes with the relay action of the tube; and finally, when the plate current is reduced to zero, renders it entirely inoperative. This form of overloading may be compensated for in the manner shown in Figure 7 by

Digitized by Google

means of an auxiliary battery in the grid circuit which makes it possible to maintain the plate current at its normal value. The effect of this auxiliary voltage in compensating for the grid charge is shown by the two curves of Figure 8. Curve A was taken with the arrangement of Figure 7 while curve B was taken in the same manner as the curves of Figure 4. The curves are self explanatory in this respect. It will be noted, however,

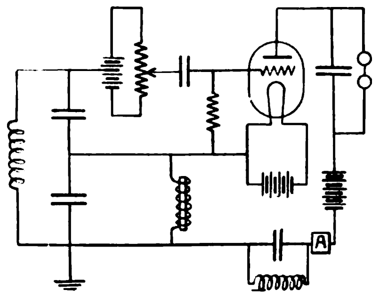


FIGURE 7

that curve A, even when the effect of overloading of grid condenser is removed, eventually shows a tendency to fall off. This is undoubtedly due to another form of overloading, caused by the radio frequency variations of the grid potential overrunning the straight part of the grid potential-plate current characteristic and thereby interfering with the audio frequency repeating action. It is difficult to determine from the heterodyne characteristics of Figure 4 whether the peaks of the curves indicate a maximum of efficiency of rectification or the beginning of the overloading of the tube. The shape of the curves indicate the latter especially on the stronger signals, but it is in any case immaterial whether the limitation of apparatus or method predominates in present-day practice. It is entirely clear that outside of the four-fold amplification of the equal heterodyne, any further amplification by increase in the local current is purely a question of improvement in efficiency.

One of the remarkable features of the curves of Figure 4 is the very rapid increase in the telephone signal strength for a relatively small change in the local current. In the case of curve A, the change from the equal heterodyne to the two-to-one ratio gave a response in the telephones four times as great as for the one-to-one ratio. The reason for this will be found in the energy relations in the tube with respect to the radio

Digitized by Google

frequency current. The rectifying characteristic shows that the charging current of the grid condenser and hence the grid potential is proportional to the square of the radio frequency current. The useful telephone current is proportional to the change in potential of the grid and hence to the square of the radio frequency current. The energy in the telephones available for producing a tone is therefore proportional to the fourth power

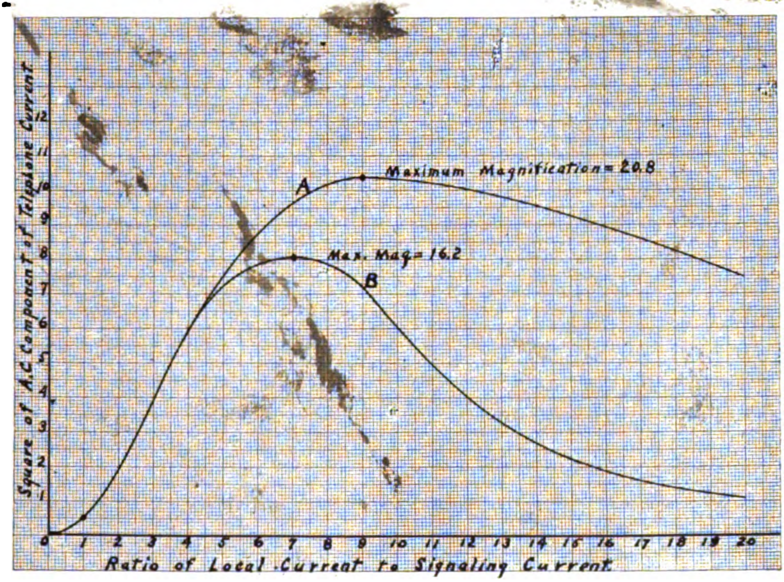


FIGURE 8

of the radio frequency current. In the case of the equal heterodyne, the variation in amplitude, assuming unity value of signaling current, is between 2 and 0, and for the 2:1 ratio it is between 3 and 1. The relative telephone currents are therefore proportional to 2^2 and (3^2-1^2) or to 4 and 8. The relative telephone signals are according to the square of these values or in the ratio of 1:4. This corresponds almost exactly with the experimental result.

The shape of the valve characteristic also explains the interesting fact discovered by Dr. Austin,* that the plate current is proportional to the second power of the radio frequency current in the non-oscillating state but to the first power in the oscillating state. In the non-oscillating state, the rectification takes place

* "Bulletin Bureau of Standards," 11, 77, Reprint 226, 1914.

Digitized by Google

on the lower part of the curve where the square law holds (with reference to zero current). In the oscillating state the operation takes place on an upper part of the curve which, for small changes of potential is practically a straight line.

It is evident from this that a regenerative receiver in the oscillating state delivers to the telephones an amount of energy which is proportional to the energy of the radio frequency current in the antenna. The relative amplitude of stray to signaling current in the telephones is therefore independent of the size of the antenna, and barring physiological effects and the possibility of overloading the tube, the readableness of signals should also be independent of antenna size. In ordinary practice this seems to be the case.

In the non-oscillating state the first power proportionality between antenna and telephone energies is maintained only for strong signals. For weak signals or even moderately strong signals the telephone current is proportional to the square of the antenna current. This means that in the working range the telephone energy will fall off very rapidly with a decrease in antenna energy with the result that the smaller the antenna the greater the ratio of the intensities of strays to signals in the telephones. Hence it follows that the larger the antenna the more readable the signals.

The relative effect of antenna size on readability of signals is well illustrated by experiences in the reception of the continuous waves of Nauen and Eilvese and the damped waves of Glace Bay at stations in the vicinity of New York. It is a well known fact that on a small antenna the German stations give more readable signals thru strays than the Glace Bay station. On a large antenna the conditions are reversed and the Glace Bay signals are by far the best.

In conclusion, the writer wishes to state that this paper does not pretend to be in any way an exhaustive treatment of the heterodyne phenomena. Only the outstanding features have been considered, but it is believed that it has been established from an experimental and physical basis that there is a very definite limit to the amplification which can be produced by the heterodyne action. The analysis of the mechanism of the amplification occurring in the electron relay receiver supports in every respect the conclusions of Liebowitz.

Digitized by Google

SUMMARY; The amplifying action of the regenerative oscillating electron relay is carefully studied. It is found, by separation of the various effects, that there exist three distinct types of amplification. The first, or ***equal heterodyne*** type, occurs when the local oscillating current is equal to the signaling current. The second, or ***optimum heterodyne*** type, occurs when the local oscillating current is increased to the critical value for maximum response. The third, or ***regenerative*** type, results from the amplifying action of the relay and its associated circuits. The roughly approximate numerical values of the three types are five-, twenty-, and fifty-fold, making a total amplification of five thousand times or more.

The mechanism of these phenomena is considered in detail with especial reference to the limitations of each process.

Digitized by Google

C. J. De Groot (by letter): Mr. Armstrong's paper has made quite clear numerous matters of interest. He has shown how many functions the vacuum amplifier may have independently and simultaneously when used as a beat receiving device of the internal heterodyne type. He has shown further how astonishingly large may be the amplification of signal thus produced by these simultaneous functions as compared to plain reception with a detector valve or tikker. The separations of these different functions and a determination of the amount which each contributes toward the total amplification including the values which have been checked by direct measurement, have indeed been thoroly planned and well executed.

There is one point for which I would submit an explanation of my own for the consideration of the speaker. This is the limitation of amplification which is found to occur for strong local currents.

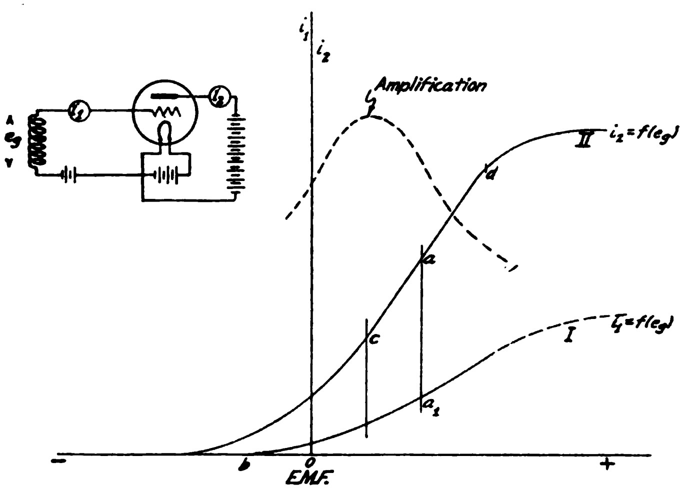
Instead of showing, as did Mr. Armstrong, the filament-to-grid characteristic, should we not rather show simultaneously two characteristics, namely the following: the filament-to-grid characteristic and the filament-to-plate characteristic. Let us suppose that the E.M.F. of both the filament heating battery and the plate circuit battery to be constant, and give these the values V_1 and V_2. Let us alter only the E.M.F. between the filament and the grid and plot the grid and plate currents as functions of this applied E.M.F. Then the two characteristics have the general shape shown in the Figure. The function of the local current is firstly to produce beats (and there is no advantage in this regard in going beyond the *equal* heterodyne), and secondly to work at a local current which brings us to the most favorable part of the characteristic for amplification.

If then we take into consideration only curve II of the Figure, we reach the conclusion that we should supply the amplifier with a local current corresponding to the point *a* of the curve, since for this part of the curve $\frac{d\,i_2}{d\,e_{gr}}$ is a maximum, and therefore the current change (or amplified signal) is greatest for a given change in E.M.F. (or incoming signal).

On the other hand, we see from curve II that working at this point implies a certain current i_1 in the grid-to-filament circuit, and this current involves a *loss of energy* in its passage thru the resistance of the circuit. Thus part of the input will

Digitized by Google

be absorbed. Since we desire a maximum amplification we must search not only for the condition where the output is a maximum (i.e., the condition corresponding to point a) but for the condition whereby this large output is attained by the smallest possible input and the condition, therefore, for which output divided by input is a maximum. Now, since the output



is a maximum near a and the input a maximum near b, it follows that the maximum amplification will be secured for a point somewhere between a and b, say at c. This condition will be reached whenever the tube is so adjusted that it works at what has been called the "optimum heterodyne." For more powerful locally generated oscillations we have to work at those points of the characteristic curve which require a considerable expenditure of input energy in the grid-to-filament circuit, and the efficiency of the device (output divided by input) is diminished. In consequence, we explain the results shown in Mr. Armstrong's curves in Figures 4 and 8 as follows: As we increase the strength of the local oscillations past the point of equal heterodyne, we cannot improve the beat production but the amplification increases because the larger local oscillating circuit (when considered in conjunction with the tube characteristics) brings us to the point a where $\frac{d\,i_2}{d\,e_{gr}}$ is a maximum. A second reason is that $\frac{d\,i_2}{d\,e_{gr}}$ increases to the point a after which it falls again, and

Digitized by Google

there should result a decrease of amplification beyond the point a. This decrease is emphasized by the fact (seen from curve I) that the larger the local oscillating current, the larger $\frac{d\,i_1}{d\,e_{gr}}$ that is, the greater the waste of input energy, $(di_1)^2r$, for the same incoming signal, $d\,e_{gr}$. A third reason for the decrease of amplification may be the fact, stated by Mr. Armstrong himself, that even working at the most suitable point of the curve (c), a strong signal may exceed the limitations of the characteristic curve II, thus giving a $\frac{\Delta\,i_2}{\Delta\,e_{gr}}$ smaller than the $\frac{d\,i_2}{d\,e_{gr}}$ for infinitesimal signals at c.

We should keep in mind that, for reasons of convenience, we have used static characteristics (as also did Mr. Armstrong) tho, strictly speaking, dynamic characteristics should be used.

The method of shifting the maximum amplification to points of higher local oscillating current as shown in Figure 8 of the paper is readily explained by the considerations here given. The steady E.M.F. applied in the grid-to-filament circuit, which is there recommended, displaces curve I horizontally relative to curve II, so that the point b of curve I is brought below point a of curve II. We can therefore work the system nearer the point a which is the point of maximum amplification. In this case the amplification should be quite independent of the signal strength as long as the signals added to the local current do not run beyond the portion cd of the curve II. For stronger signals a decrease of amplification will occur because of the general shape of curve II.

Edwin H. Armstrong (by letter): Dr. de Groot has raised a very interesting point concerning the factors which limit the amplification obtainable by the optimum heterodyne. It is in line with the explanation of Liebowitz when the electrostatic telephone is the detecting agency; viz.: that the increase in efficiency of the detecting apparatus as the auxiliary current is increased creates a counter E.M.F. or an increase in the effective resistance of the circuit to which it is connected. I expected to find that this increase in effective resistance of the main circuit would be the most predominant factor in limiting the amplification obtainable by the optimum heterodyne and was exceedingly astonished to find that the effect was a relatively unimportant one.

This was readily determined with the arrangement of Figure 1

Digitized by Google

and the experiment was made in the following way. With condenser C_2 short-circuited to eliminate the regenerative feature and with a predetermined value of signaling current, the equal and optimum heterodyne telephone currents were measured. A resistance of 5,000 ohms was then introduced into circuit N between the loading coil of the circuit and the coupling coil connecting it with the antenna. The signaling current was restored to its initial value by increasing the power of the system X, and the equal and optimum heterodyne currents again measured. Little difference was observed in the amplification obtainable with the low resistance circuit, which measured about 300 ohms and the high resistance circuit which was approximately 5,300 ohms, and this, in itself, is conclusive evidence that the effective limitation is not due to an increased resistance in the main circuit. Further investigation developed that the predominant limiting factors lie along those lines presented in the paper.

The result was so unexpected that some further experiments were made with a view of determining, if possible, the reason for the absence of the phenomena so clearly brought out by Dr. de Groot. While lack of opportunity prevented a complete investigation, the reason appears to be in the fact that the relay, which was of the same structure as the standard de Forest audion, did not fit efficiently into the circuit to which it was connected. The relay contributed only about 15 per cent. of the total effective resistance of the circuit, and it was hardly possible to improve this very much and still keep the capacity across which the relay was connected at a reasonable value. About 0.0004 microfarad was normally used, which is, perhaps, as low as good commercial practice permits. As a consequence of this low efficiency, other factors exert their influence upon the maximum amplification before the increase in efficiency of the detector produces any noticeable effect. The practical significance of this is that the tube used was ill adapted to fit into ordinary commercial circuits, and that a larger tube could be more efficiently used. Aside from the relative magnitude of the effect indicated by Dr. de Groot, I am entirely in accord with the points he has so clearly presented.

Carl Ort (by letter): The paper under consideration constitutes a very thoro investigation of the so-called "heterodyne" receivers, and shows that this system, when used in conjunction with a rectifying detector, operates on an entirely different

Digitized by Google

principle from that explained by Messrs. J. L. Hogan, Jr., and L. Cohen. Professor Fessenden first used a sustained wave oscillator for the purpose of producing beat tones in the receiver. As far as the patent literature or other publications indicate, he used an electromagnetic receiver; and later, when it was shown by Mr. Rieger and myself that the electrostatic receiver could be made very sensitive by proper construction (see articles on condenser receivers in "Elektrotechische Zeitschrift," 1909, page 655 and "Archiv für Elektrotechnik," 1, 1912 page 192) he replaced the electromagnetic receiver by an electrostatic one with much success. Mr. Lee and Mr. Hogan later replaced the electrostatic receiver by a crystal detector (See the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 1, July, 1913, and U. S. patent 1,141,717) with the result that much higher sensitiveness was obtained than with any previous receiving system. Messrs. Hogan and Cohen explained the large amplification by assuming that the process amplifies the received antenna energy, and that the crystal detector rectifies merely this amplified energy. But it was shown by Mr. B. Liebowitz that the maximum amplification of this combination should be 4. (See the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 1915, page 185). Mr. Armstrong's experiments have shed new light on these phenomena and have indicated that the amplification obtained with a rectifying detector depends on the energy of the local oscillations which are applied to the detector, and that while the energy received is not magnified at all, the sensitiveness of the detector is increased. This increase is independent of the frequency of oscillation of the local source.

It may be of interest to describe some experiments which I began in December, 1912, in a small town in Austria. At the time I was carrying on radiophone experiments, using a small Poulsen arc as a transmitting source. One day it happened that I received not only the speech from my arc station but also the noon time signals of the German Post Office station at Norddeich. This latter station was distant from my home about 380 miles (600 km.), the entire distance being over mountainous land. Two things struck me at once. To begin with, I was impressed by the great distance over which I was receiving with my small antenna, this being only about 30 feet (9 m.) high and about 90 feet (27 m.) long. Furthermore, I noticed that the tone of the signals received with a crystal detector was no longer musical but resembled that obtained when a tikker was used. (The Norddeich station sends out noon signals

Digitized by Google

with a 10 K. W. Telefunken quenched spark transmitter, with a 1,000 cycle note). Later I investigated the latter phenomenon, applying sustained oscillations directly to the detector, and found that the amplification was due to the increase of sensitiveness of the detector. Every integrating (rectifying) detector showed this characteristic. I found that the amplification could be obtained with any frequency not audible to the human ear. The limit of amplification was determined by the maximum impressed voltage of sustained radio frequency at which the detector burned out. I was able to obtain amplifications of about 20-fold. In order to explain this effect, I applied the polarisation theory given for the condenser receiver (as cited above), stating that the amplification was proportional to $(i_1+i_2)^2=i_1^2+2\,i_1\,i_2+i_2^2$ where i_1 is the received current and i_2 the local current produced in the detector circuit by the local source of sustained oscillations. I called this phenomenon the "polarisation of integrating detectors" because every detector with a rectifying characteristic can be polarised in this way by applying a polarisation radio frequency sustained voltage at its terminals. For this reason the latter term may be applied to this method in place of the "equal and optimum heterodyne" designation used by Mr. Armstrong. From the very beginning of my experiments I considered the production of beats by this method when used for receiving sustained oscillations as a natural consequence. However, it is not at all necessary to produce beats for receiving sustained oscillations when this method is used with equal frequencies and an Einthoven thread galvanometer is used as an indicating instrument. The same amplifying effect is then obtained, and I do not see any reason why it should be called a "heterodyne" method in this case. The same amplifying effect can be used at equal frequency for radio telephony.

It is unnecessary for me to explain the great advantages of the "polarised integrating method" because they are very well known to the readers of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS. The purpose of this communication is merely to indicate my part in the development of this method. Mr. Armstrong's paper and Mr. Liebowitz's conclusions verify the conclusions which I drew from my observations four years ago, but could not publish for patent reasons and because of war conditions abroad.

Edwin H. Armstrong (by letter): As Mr. Ort points out, the function of the auxiliary circuit, when carried beyond the

Digitized by Google

"equality of current" stage, is a polarizing one, and in the present case the phenomenon referred to as the optimum heterodyne is that of a polarised integrating detector. The terms "equal and optimum heterodyne" were used purely for purposes of convenience of reference, and if more suitable terms be suggested, we should, of course, employ them. In view of Mr. Ort's proposals, I would suggest that the matter be taken under consideration by the Committee on Standardization of THE INSTITUTE OF RADIO ENGINEERS.

Lee de Forest (by letter): I doubt if the simplicity of Mr. Armstrong's explanations of audion phenomena is satisfying to those who have extensively experimented with the audion.

For example, readers of his previous paper on the audion might well be satisfied with his theory of the rectification phenomena which obviously *must* there occur—until there transpires the simple experiment of making all three audion electrodes incandescent! The fact that the audion action is thereby unaffected, while the Edison hot-to-cold rectification is made impossible is yet to be explained by the advocates of the Fleming valve theory.

Similarly, in criticism of the too simple explanations advanced in the present paper, an easy experiment with the incandescent grid shows that the ultraudion amplifying processes are unaffected. And it is well known that with the proper audion and "wing-and-grid" oscillating circuits, a grid-charging or "*C*" battery is unnecessary to obtain a maximum efficiency detector of sustained oscillations.

These are experimental facts and not theory, and Mr. Armstrong must search more deeply before the ultimate explanation of audion phenomena is revealed.

This writer has sophistically misinterpreted my discussion on Dr. Austin's recent paper (PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 4, number 3, page 266). There is nothing therein contained to lead any one to suppose that I am an advocate of the unconstitutionality of the law of the conservation of energy.

Edwin H. Armstrong (by letter): In reference to Dr. de Forest's discussion, I feel that he must have failed in some way to understand the present paper because his discussion clearly seems to apply not to the present paper but to some of the more faundamental and elementary matters which were published by me several years ago. However, in view of the part which the

Digitized by Google

fundamental theory played in the Fleming valve litigation of recent date, I take the present opportunity of laying before the membership of the INSTITUTE the details of what has been to me a most interesting controversy.

During the course of the litigation in question (Marconi vs. de Forest), plaintiffs introduced as evidence showing infringement an article on the operation of the audion which I published in the "Electrical World" of December 12, 1914. This article showed clearly, with oscillographic proof, the manner of the filament-to-grid valve action as well as other methods of use for producing rectification. A most determined effort was made by the de Forest experts and counsel to invalidate the theory. About fifty pages of testimony were introduced showing experiments designed to prove that when signals were received, the charge on the grid became *positive* and hence that any theory of rectification based on the grid becoming negative was incorrect. It was stated that these experiments had been repeated and confirmed by the United States Bureau of Standards.

The manner in which these tests had been made was briefly as follows. A voltmeter consisting of a sensitive galvanometer in series with a resistance of the order of a megohm was connected between the grid and filament of an audion which was arranged in the usual way with a tuned circuit and stopping condenser. Coupled with this tuned circuit was a second tuned circuit driven by a buzzer exciter. It was stated by the de Forest experts that when the circuits were excited and radio frequencies applied to the grid the deflection of the voltmeter showed a positive charge on the grid. I repeated these experiments with buzzer excitation and under certain conditions found that the voltmeter would indicate a positive charge on the grid, but that when the receiver was connected to an antenna and outside signals were received, the grid invariably became *negative*. Investigation showed immediately that a rather curious effect produced on the tube by the high voltage across the break of the buzzer was responsible for the apparent indication of a positive charge. I was able to testify in court to these interesting facts with the result that counsel for the de Forest Company were forced to withdraw all fifty pages of testimony and *admit on the record that the grid became negatively charged.* After this collapse of the positively charged grid theory, the defense built up another based on a "sensitive medium" ionized to an "optimum value" and constructed an audion with an incandescent grid to prove that rectification was not essential to the operation of the

Digitized by Google

device as a detector. The manner of operation of this device will appear from the oscillograms of Figures 11 and 12 of the "Electrical World" article from which it will be obvious that the rectifying action of the tube will continue irrespective of the temperature of the grid.

In upholding the validity of the Fleming patent and finding that the use of the audion as a detector was an infringement thereof, the Court stated that the "Electrical World" article might be considered as read into his opinion. In view of this fact and in view of the fact that the theory has withstood intact the test of publication and discussion in the PROCEEDINGS, the controversy must now be considered as settled, and I must refuse to enter into any further discussion of these elementary matters.

Digitized by Google

VOLUME 5 JUNE, 1917 NUMBER 3

PROCEEDINGS
of
The Institute of Radio Engineers
(INCORPORATED)

TABLE OF CONTENTS

PROCEEDINGS OF THE SECTIONS
AND INSTITUTE NOTICE

TECHNICAL PAPERS AND DISCUSSIONS

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

PUBLISHED EVERY TWO MONTHS BY
THE INSTITUTE OF RADIO ENGINEERS, INC
ONE HUNDRED AND ELEVEN BROADWAY
NEW YORK

THE TABLE OF CONTENTS FOLLOWS ON PAGE 171

Digitized by Google

GENERAL INFORMATION

The right to reprint limited portions or abstracts of the articles, discussions, or editorial notes in the Proceedings is granted on the express condition that specific reference shall be made to the source of such material. Diagrams and photographs in the Proceedings may not be reproduced without securing permission to do so from the Institute thru the Editor.

Those desiring to present original papers before the Institute of Radio Engineers are invited to submit their manuscript to the Editor.

Manuscripts and letters bearing on the Proceedings should be sent to Alfred N. Goldsmith, Editor of Publications, The College of the City of New York, New York.

Requests for additional copies of the Proceedings and communications dealing with Institute matters in general should be addressed to the Secretary, The Institute of Radio Engineers, 111 Broadway, New York.

The Proceedings of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings in New York, Washington, Boston or Seattle.

Payment of the annual dues by a member entitles him to one copy of each number of the Proceedings issued during the period of his membership. Members may purchase, when available, copies of the Proceedings issued prior to their election at 75 cents each.

Subscriptions to the Proceedings are received from non-members at the rate of $1.00 per copy or $6.00 per year. To foreign countries the rates are $1.10 per copy or $6.60 per year. A discount of 25 per cent. is allowed to libraries and booksellers. The English distributing agency is "The Electrician Printing and Publishing Company," Fleet Street, London, E. C.

Members presenting papers before the Institute are entitled to ten copies of the paper and of the discussion. Arrangements for the purchase of reprints of separate papers can be made thru the Editor.

It is understood that the statements and opinions given in the Proceedings are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

COPYRIGHT, 1917, BY

THE INSTITUTE OF RADIO ENGINEERS, INC.

ONE HUNDRED AND ELEVEN BROADWAY

NEW YORK, N. Y.

Digitized by Google

CONTENTS

Digitized by Google

OFFICERS AND BOARD OF DIRECTION, 1917

(Terms expire January 2, 1918; except as otherwise noted.)

PRESIDENT
MICHAEL I. PUPIN

VICE-PRESIDENT
JOHN L. HOGAN, JR.

TREASURER
LOUIS R. KRUMM

SECRETARY
DAVID SARNOFF

EDITOR OF PUBLICATIONS
ALFRED N. GOLDSMITH

MANAGERS

(Serving until January 7, 1920)

ERNST F. W. ALEXANDERSON
JOHN STONE STONE

(Serving until January 1, 1919)

EDWIN H. ARMSTRONG
GEORGE S. DAVIS

(Serving until January 2, 1918)

LOUIS W. AUSTIN
JOHN HAYS HAMMOND, JR.
LLOYD ESPENSCHIED
WARREN F. HUBLEY
ROY A. WEAGANT

ADVERTISING MANAGER
LOUIS G. PACENT

WASHINGTON SECTION

EXECUTIVE COMMITTEE

CHAIRMAN
LIEUT.-COLONEL GEORGE O. SQUIER
War Department,
Washington, D. C.

SECRETARY-TREASURER
GEORGE H. CLARK
Navy Department,
Washington, D. C.

CHARLES J. PANNILL
Radio, Va.

BOSTON SECTION

CHAIRMAN
A. E. KENNELLY,
Harvard University,
Cambridge, Mass.

SECRETARY-TREASURER
MELVILLE EASTHAM,
11 Windsor Street,
Cambridge, Mass.

SEATTLE SECTION

CHAIRMAN
ROBERT H. MARRIOTT,
715 Fourth Street,
Bremerton, Wash.

SECRETARY-TREASURER
PHILIP D. NAUGLE,
71 Columbia Street,
Seattle, Wash.

Digitized by Google

SAN FRANCISCO SECTION

CHAIRMAN	SECRETARY-TREASURER
W. W. Hanscom,	V. Ford Greaves,
848 Clayton Street,	526 Custom House,
San Francisco, Cal.	San Francisco, Cal.

H. G. Aylsworth
145 New Montgomery Street,
San Francisco, Cal.

PAST-PRESIDENTS

SOCIETY OF WIRELESS TELEGRAPH ENGINEERS

John Stone Stone, 1907–8 Lee De Forest, 1909–10
Fritz Lowenstein, 1911–12

THE WIRELESS INSTITUTE

Robert H. Marriott, 1909–10–11–12

THE INSTITUTE OF RADIO ENGINEERS

Robert H. Marriott, 1912 Greenleaf W. Pickard, 1913
Louis W. Austin, 1914 John Stone Stone, 1915
Arthur E. Kennelly, 1916

STANDING COMMITTEES

1917

COMMITTEE ON STANDARDIZATION

John L. Hogan, Jr., *Chairman*	Brooklyn, N. Y.
E. F. W. Alexanderson	Schenectady, N. Y.
Edwin H. Armstrong	New York, N. Y.
Louis W. Austin	Washington, D. C.
Ferdinand Braun	Strassburg, Germany
A. A. Campbell Swinton	London, England
George H. Clark	Washington, D. C.
William Duddell	London, England
Leonard Fuller	San Francisco, Cal.
Alfred N. Goldsmith	New York, N. Y.
Guy Hill	Washington, D. C.
Lester Israel	Washington, D. C.
Frederick A. Kolster	Washington, D. C.
George H. Lewis	Brooklyn, N. Y.
Valdemar Poulsen	Copenhagen, Denmark
George W. Pierce	Cambridge, Mass.

Digitized by Google

John Stone Stone	New York, N. Y.
Charles H. Taylor	New York, N. Y.
Roy A. Weagant	. Roselle, N. J.
Jonathan Zenneck	Munich, Germany

COMMITTEE ON PUBLICITY

David Sarnoff, *Chairman*	New York, N. Y.
John L. Hogan, Jr.	Brooklyn, N. Y.
Robert H. Marriott	. Seattle, Wash.
Louis G. Pacent	New York, N. Y.
Charles J. Pannill	. Radio, Va.
Robert B. Woolverton	San Francisco, Cal.

COMMITTEE ON PAPERS

Alfred N. Goldsmith, *Chairman*	New York, N. Y.
George H. Clark	Washington, D. C.
Melville Eastham	Cambridge, Mass.
John L. Hogan, Jr.	Brooklyn, N. Y.
Alexander Meissner	Berlin, Germany
Sir Henry Norman	London, England
Wichi Torikata	. Tokyo, Japan

SPECIAL COMMITTEES

COMMITTEE ON INCREASE OF MEMBERSHIP

Warren F. Hubley, *Chairman*	. Newark, N. J.
J. W. B. Foley	Port Arthur, Tex.
Lloyd Espenschied	New York, N. Y.
John L. Hogan, Jr.	Brooklyn, N. Y.
David Sarnoff	New York, N. Y.

Digitized by Google

PROCEEDINGS OF THE SECTIONS OF THE INSTITUTE

WASHINGTON SECTION

A meeting of the Washington Section of The Institute of Radio Engineers was held at the Commercial Club in Washington on the evening of Saturday, March 7, 1917. The dinner was in honor of the accession of Brigadier-General George O. Squier, Chairman of the Washington Section, to the office of Chief Signal Officer of the U. S. Army. The meeting was largely attended. Congratulatory telegrams to General Squier were received from President Pupin of the Institute and Professor Goldsmith.

BOSTON SECTION

A meeting of the Boston Section of the Institute was held at the Cruft High Tension Laboratory, Harvard University, on the evening of Thursday, January 18, 1917. Mr. H. B. Lawther presented a paper entitled "Resistance and Capacity of Condensers at Frequencies from 30 to 10,000,000 Cycles per Second." This was followed by a description, from Dr. E. L. Chaffee, of an absolute method of calibrating wave meters. The description was accompanied by an experimental demonstration.

On the evening of Wednesday, February 21, 1917, a meeting of the Boston Section was held at the Cruft High Tension Laboratory. Dr. David L. Webster presented a paper on "X-Rays and Crystal Structure."

SEATTLE SECTION

A meeting of the Seattle Section of the Institute was held at Denny Hall, University of Washington, Seattle on the evening of January 6, 1917, Chairman Robert H. Marriott presiding. A paper on "The Measurement of Radio Telegraphic Signals with the Oscillating Audion" by Dr. Louis W. Austin was presented. The attendance was sixteen.

On the evening of February 9, 1917, a meeting of the Seattle Section was held at the Y. M. C. A. in Seattle, Mr. R. H. Marriott presiding. The attendance was eighteen. Certain national radio matters and the financial affairs of the Section were discussed.

Digitized by Google

SAN FRANCISCO SECTION

A meeting of the San Francisco Section of the Institute was held at the Engineers' Club in San Francisco on the evening of January 16, 1917, Mr. W. W. Hanscom presiding. The attendance was forty-six. A paper by Mr. E. T. Cunningham on "Historical Sketch and Some Theories of Vacuum Detectors" was read, and discussed by Messrs. Roos, Hanscom, and Burglund. A paper on "The Manufacture of Vacuum Detectors" was then read by Mr. O. B. Moorhead, and discussed by Messrs. Hanscom, Cookson, Cunningham, and Greaves. A third paper on "The Characteristic Temperature Curves of Vacuum Detectors" was presented by Mr. Haraden Pratt, and discussed by Mr. Burglund and others. Previous to the technical meeting, a Section Dinner was held in the club rooms, and was attended by fourteen. Members of the Engineers' Club and of the Telephone Company were invited to the meeting.

On the evening of February 20, 1917, a meeting of the San Francisco Section was held at the Engineers' Club, Mr. W. W. Hanscom presiding. The attendance was thirty. A paper on "Engineering Precautions in Radio Installations" by Mr. Robert H. Marriott was presented. It was discussed by Messrs. W. W. Hanscom and T. M. Stevens. A formal discussion on the paper together with further data was then presented by Mr. Ellery W. Stone, and this was discussed by Messrs. V. Ford Greaves, Secretary of the Section, O. C. Roos, and W. W. Hanscom. Thereafter Mr. E. W. Stone was appointed Chairman of the Social and Entertainment Committee, and Mr. O. C. Roos was appointed a member of this committee.

On the evening of March 20, 1917, a meeting of the San Francisco Section was held at the Engineers' Club, Mr. W. W. Hanscom presiding. The attendance was forty-two. Mr. L. F. Fuller presented an abstract and discussion of Professor P. O. Pedersen's paper on "The Poulsen Arc and Its Theory." The discussion was carried on by Messrs. Hanscom, Stone, Sprado, Roos, and Pratt. This was followed by a discussion of a bill then pending relative to radio regulation. A Committee on Papers, consisting of Mr. Haraden Pratt was appointed, Mr. Pratt to serve with the Executive Committee. The Membership Committee was appointed as follows: Mr. H. W. Dickow, Chairman, Messrs. H. Berringer, and H. D. Hayes. The Committee on Modern Practice was constituted as follows: Mr. A. A. Isbell, Chairman, Messrs. T. M. Stevens, and O. B. Moorhead.

Digitized by Google

The Institute of Radio Engineers announces with regret the death of

Mr. Francis P. Miller

(Experimenter and Radio Operator, of Los Angeles, California, and associated with the Institute)

Digitized by Google

THE NEW YORK
PUBLIC LIBRARY
ASTOR, LENOX
TILDEN FOUNDATIONS.

Digitized by Google

UNITED STATES RADIO DEVELOPMENT*

By

Robert H. Marriott, B.Sc.

(Past President of the Institute of Radio Engineers, Expert Radio Aide, U. S. N.)

Before taking up the radio development of the United States as a whole, some of the more notable instances of Pacific Coast development will be cited. The Pacific Coast is particularly noteworthy for early construction *combined* with *lasting* construction.

The first *permanent* Commercial Public Service radio station in the United States, using U. S. built apparatus, was constructed at Avalon, Santa Catalina Island, California in the spring of 1902.

At the same time this station became the first *permanent* station in the United States to adopt exclusively the telephone method of reception.

The first *permanent* radio trans-oceanic service from United States soil was established between California, near San Francisco, and Honolulu in 1912. Also these were the first stations permanently to use the constant amplitude type of transmitters.

The first Permanent, Commercial, Overland, Public Service, Radio Stations using Constant Amplitude transmitters in the United States were established by the Federal Telegraph Company, between San Francisco and Los Angeles in 1911.

At an early date the Army constructed stations at Nome and St. Michaels, which, from 1904 on, became known for the comparative reliability with which they rendered radio service between these points.

We may now take up radio development in the United States as a whole. In numerical results given in this paper, only

* A paper delivered before a joint meeting of the American Institute of Electrical Engineers and The Institute of Radio Engineers at the Panama Pacific Convention, San Francisco, September 17, 1915. This paper is based on Government records as found by the writer, and on the writer's notes and recollection. The records and notes are too voluminous to include in a paper of this kind; for example, about 3,000 sheets were used to classify and enumerate the radio transmitters.

Digitized by Google

Government stations and stations established for commercial purposes have been included because it was found that the number of experimental stations, their date of use and the apparatus used, was indefinite, extremely complicated, and required lengthy explanation.

Considering Chart 1 marked United States "Wireless" Telegraph Development (transmitters):

This chart shows the total number of transmitters and the total number of each class of transmitters for each year from 1899 to 1915, together with manufacturers of these transmitters and operating organizations.

PLAIN ANTENNA TRANSMITTERS (P. A. Class) shown in black includes the type of transmitters wherein the antenna was connected to one side and the ground to the other side of the spark gap of an induction coil.

TUNED COUPLED CIRCUIT TRANSMITTERS (C. T. Class) shown in heavy diagonal lines, includes, for example, the transmitters where an antenna in series with an inductance was tuned to the same frequency, and inductively coupled to a circuit containing a plain spark gap in series with an inductance and leyden jars. United Wireless Telegraph Company transmitters were commonly of this type.

IMPULSE EXCITATION TRANSMITTERS (I. E. Class) shown in lighter diagonal lines, includes, for example, the quenched gap type of apparatus. The Telefunken Company transmitters were commonly of this type.

CONSTANT AMPLITUDE TRANSMITTERS (C. A. Class) shown in white, includes transmitters which produce constant amplitude alternating current in the antenna. Federal Telegraph Company arc transmitters, and radio frequency alternators are included under this class.

With the exception of the number of stations equipped with the different classes of transmitters and the names of Companies, the points in this chart are contained in a general way in Chart 2 and its discussion.

CURVE *R* at the top is intended to indicate the approximate maximum distances used for public or government service each year from 1899 to 1915 referred to the numerals at the left reading from 0 to 4,000 and marked "Range in Miles." (1 mile = 1.6 km.)

CURVES *T*, *S*, *L*, *V*, and *G* are intended to indicate the number of stations each year from 1899 to 1915 referred to the

Digitized by Google

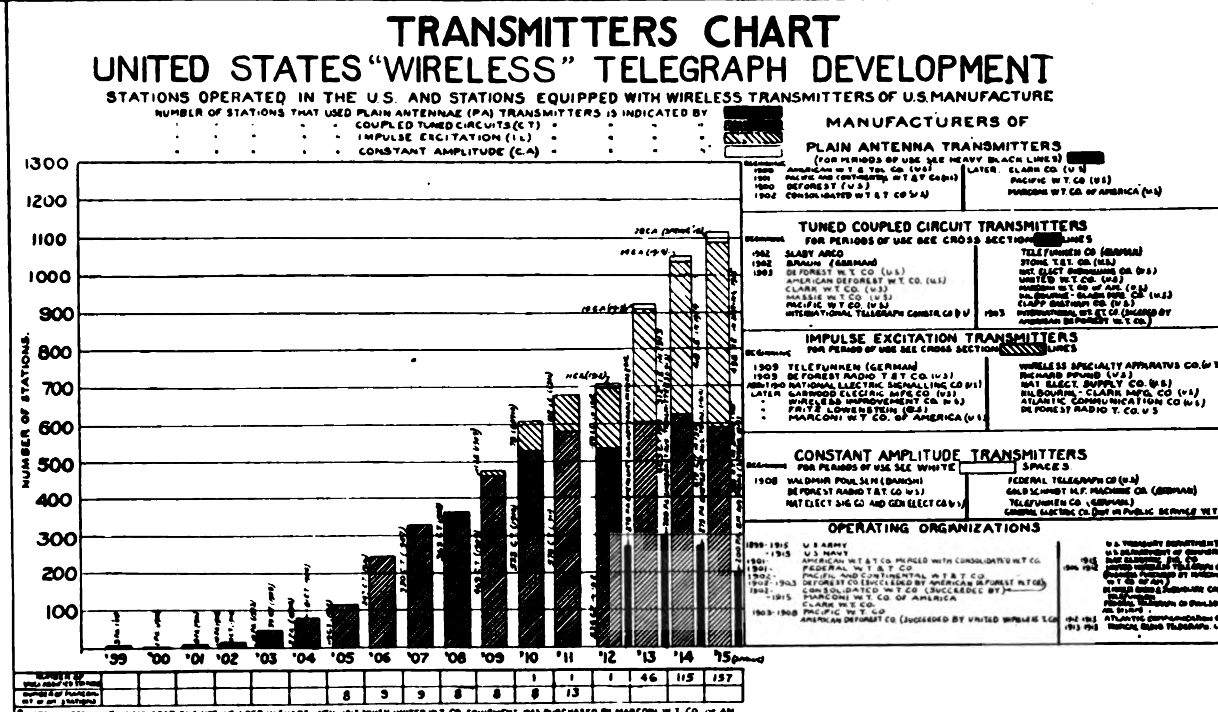
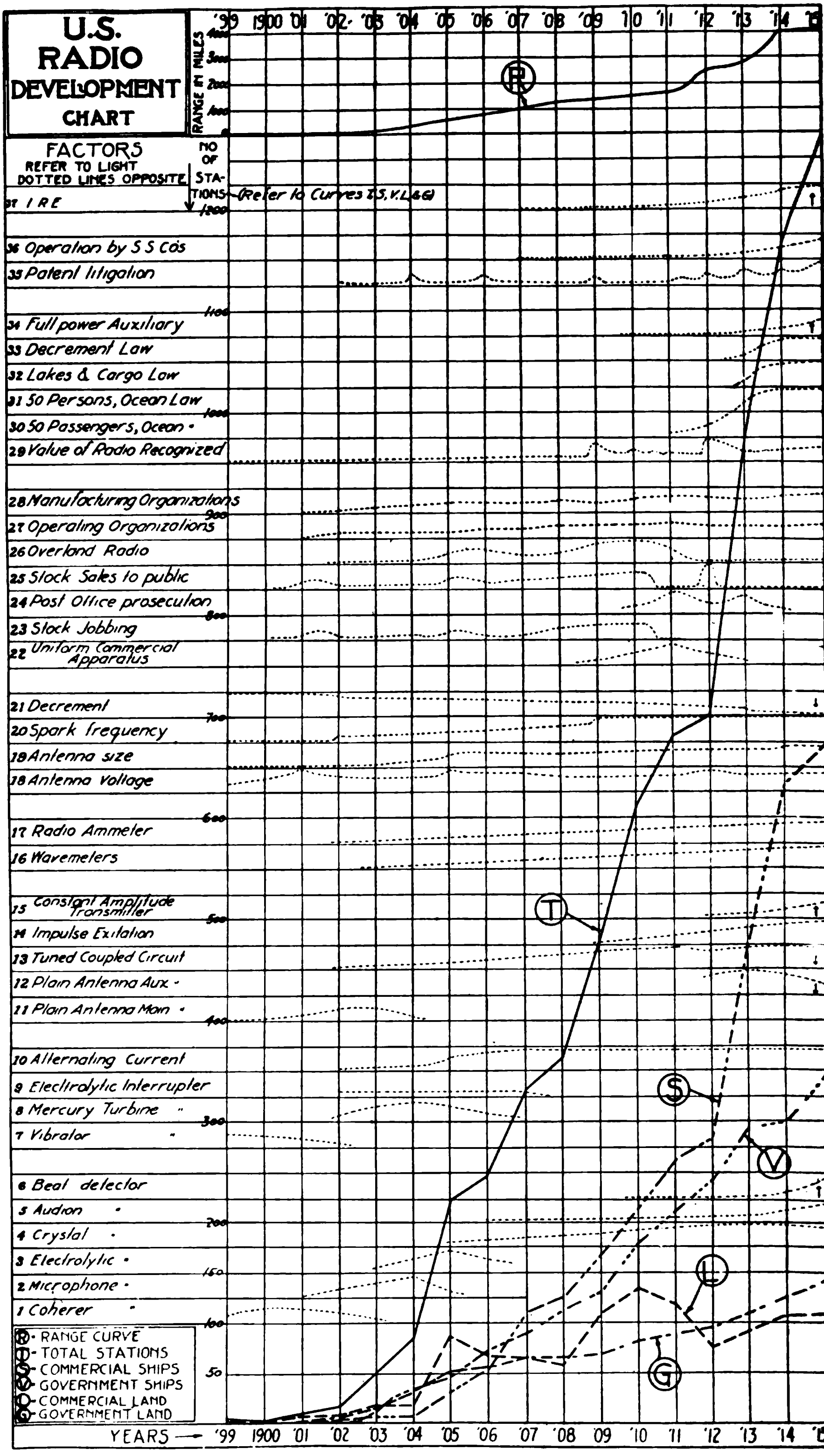

TRANSMITTERS CHART
UNITED STATES "WIRELESS" TELEGRAPH DEVELOPMENT
STATIONS OPERATED IN THE U.S. AND STATIONS EQUIPPED WITH WIRELESS TRANSMITTERS OF U.S. MANUFACTURE
NUMBER OF STATIONS THAT USED PLAIN ANTENNAE (PA) TRANSMITTERS IS INDICATED BY
COUPLED TUNED CIRCUITS (C.T.)
IMPULSE EXCITATION (I.E.)
CONSTANT AMPLITUDE (C.A.)
MANUFACTURERS OF
PLAIN ANTENNA TRANSMITTERS
TUNED COUPLED CIRCUIT TRANSMITTERS
IMPULSE EXCITATION TRANSMITTERS
CONSTANT AMPLITUDE TRANSMITTERS
OPERATING ORGANIZATIONS
NUMBER OF STATIONS
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
'99
'00
'01
'02
'03
'04
'05
'06
'07
'08
'09
'10
'11
'12
'13
'14
'15

Chart 1



UNITED STATES RADIO DEVELOPMENT CHART 2

Numerals at the top and bottom of this chart indicate years

Digitized by Google

numerals at the left reading from 0 to 1,200 and under the heading "Number of Stations."

These curves, particularly in latter years, lag somewhat because it frequently happened that the existence of stations was not recorded or was unknown to the writer until the following calendar year. Data for 1915 was brought up to about June 1.

Curve *T*—Total number of radio stations in the United States. (Government and commercial)

Curve *S*—Number of commercial ship stations

Curve *L*— " " " land "

Curve *V*— " " Government ship "

Curve *G*— " " " land "

Under the heading of "Factors" at the left on chart 2 is a list of subjects, numbered on the extreme left. The lighter dotted curves extending across the chart in the single narrow spaces opposite these subjects are intended to indicate approximately the rising, falling, peaks, and depression in the history of these subjects or factors.

1. Coherer. This form of detector was used in the Navy stations in 1899. Apparently coherers of English Marconi Company and Navy make were used. Owing to its insensitiveness and uncertainty of action, the coherer was almost entirely discarded in the United States by 1903 as, indicated by the light dotted line opposite "Coherer" on the Chart. Changing from the coherer was one of the greatest steps, not only by virtue of increased sensitiveness and reliability, but by leading to detectors more capable of utilizing long wave trains thereby making it easier to construct more powerful transmitters.

2. Microphone. This is intended to include the class of detectors which superseded and took the place of the coherer. As a rule, they consisted of a contact between steel and carbon, or steel and aluminum; however, the detectors as used at Avalon and Whites Point, California, consisted of the contact between steel and an oxide of iron (and thus may have had more of the qualities of the crystal detectors). The microphone was abandoned largely because of its lack of stability.

Digitized by Google

The arrival of the microphone marks the arrival of the lasting telephone method of reception, a revolutionary and comparatively large step in radio advancement.

3. ELECTROLYTIC. This detector succeeded, and took the place of the microphone. At its best it was very sensitive but atmospherics destroyed its extreme sensitiveness and the acid used in it damaged other things. A court decision tending to give Mr. Fessenden and his associates a patent monopoly on this form of detector apparently hastened its disapproval and disappearance.

4. CRYSTAL. This detector succeeded and took the place of the electrolytic partly because it was cheaper and more stable and partly because the United Wireless Telegraph Company, the commercial company having the greatest number of stations at that time, controlled the use of the carborundum detector.

Also, the Government became active in the use of silicon and perikon (zincite and chalcopyrite). Galena and various combinations with zincite came into use. These crystal detectors have been used in greater number than any other since about 1907.

5. AUDION. This form of detector was used to some extent as early as 1906, but apparently in very small numbers until about 1912 when the amateurs became active in its use, and within the last year or more it has been used to some extent by the Government.

The TIKKER detector, not shown in the Chart, was mainly used in 1912 and 1913 for receiving constant amplitude waves.

6. BEAT detector. This form of detector consists, in part, of a radio frequency, constant amplitude generator supplying a radio frequency differing from the frequency of the incoming, constant amplitude signals by such an amount as will produce audible beats. This appeared some time ago, to a very limited extent, in what was called the "heterodyne," wherein an arc produced the local radio frequency.

Within the last year or more, detectors, of which the audion is one type, have been arranged to act as detectors and local generators. This comparatively simple form of beat detector is taking the place of the tikker and increasing in number with the increase in use of constant amplitude transmitters.

Digitized by Google

The pliotron and other detectors and oscillators are increasing in numbers with the audion, particularly for beat reception.

These successive detectors, and the telephone method of reception, together with the subsequent improvements in telephone receivers and tuner circuits, have obviously contributed to radio service and to the rise of the range curve *R*, shown at the top of the chart.

All of the detector steps were markedly useful in radio development, but those recent steps of which the audion and pliotron are types (with their three-fold abilities, as detectors, generators and amplifiers), stand out as particularly useful. And the possibility of tuning to group frequency adds encouragement to the thought of better selectivity for the future.

7. The Vibrator Interrupter used first as a means of breaking the primary current in the induction coil, because of its unreliability, small current carrying capacity, and slow operation was abandoned quite early by most United States users; the chief exception being the American Marconi Company, which brought it back into use in considerable quantity in 1912 in connection with the auxiliary 10-inch coil supplied by them and indicated under Factor 12. However, it has again been condemned and is passing out.

8. The Mercury Turbine Interrupter replaced the vibrator to some extent. This interrupter was capable of giving a much higher interruption rate per second and to some extent was more reliable; however, the mercury required frequent cleaning and was somewhat expensive and injurious.

At the Avalon and Whites Point, California Stations, in 1902, rotating commutators were used. These were more reliable and gave higher interruption frequency than the vibrator.

9. The Electrolytic Interrupter came with the mercury turbine interrupter, as a part of German made apparatus, supplied to the U. S. Navy in 1902. It, too, produced higher interruption frequency, but varied in action and became less satisfactory as its temperature increased and the acid used was injurious.

10. Early in 1903, Dr. de Forest brought an *alternating current generator and transformer* to the Navy Department at Annapolis. This was the beginning of the marked advancement in power and reliability at the transmitter. And the alternating current has lasted up to the present time.

Digitized by Google

The mercury turbine and electrolytic helped to increase the range and service, while the alternating current contributed to a greater and more lasting extent.

11. The PLAIN ANTENNA TRANSMITTER was used by the United States Navy as early as 1899 at the Atlantic Highlands near New York and on vessels. At this time, it appeared with the vibrator interrupter and coherer detector.

12. The PLAIN ANTENNA TRANSMITTER as an auxiliary was brought back by the American Marconi Company in 1912. The plain antenna transmitter was the characteristic transmitter of Marconi Companies.

13. The TUNED COUPLED-CIRCUIT TRANSMITTERS made by the Slaby-Arco Company of Germany were used by the United States Navy at Annapolis and on vessels in the Fall of 1902. Tuned coupled circuit transmitters later became the characteristic transmitters of the de Forest and United Wireless Telegraph Companies.

14. The IMPULSE EXCITATION TRANSMITTERS made by the Telefunken Company of Germany and by Dr. Seibt of Germany (then with the de Forest Radio Telephone and Telegraph Company) were put in use almost simultaneously in 1909. The Telefunken transmitters were used shortly thereafter by the Navy and Army. Later the quenched gap transmitters became known as the characteristic transmitter of the Telefunken Company.

15. CONSTANT AMPLITUDE TRANSMITTERS of the arc type were used in commercial radio Service in 1912, and have become known as the characteristic transmitters of the Federal Telegraph Company. The Goldschmidt alternator type came into service at Tuckerton in 1914, and the frequency-changing transformer type came into service at Sayville in 1915.

Before 1912, constant amplitude generators were built and experimented with in an endeavor to obtain serviceable machines, and for calibrating purposes.

The RADIO TELEPHONE has been experimented with in varying amount since about 1907, but up to the middle of this year it apparently has never been sufficiently marked in its usefulness to remain in Government or commercial use. Apparently the main reasons have been: 1: inability to construct a telephone transmitter (e. g. microphone) which would reliably

Digitized by Google

modulate sufficient energy; and 2: difficulty in obtaining constant amplitude current at short wave lengths or satisfactory spark frequency above audibility. The pliotron and similar devices may serve in solving these difficulties.

The word "radio" came into marked use in place of "wireless" in 1907, and was officially adopted by The Institute of Radio Engineers in 1911 and shortly thereafter by the United States Government.

16. WAVE METERS of German make were used by the Navy Department early in 1903, and stations were adjusted to prescribed wave lengths with increasing accuracy up to the present. Also, Navy records made about that time or shortly after show resonance curves. The wave meter was used in the United Wireless Company in 1907 and increased in use, until in 1910, practically all the United Wireless (the then largest commercial company) stations were adjusted by using the wavemeter.

17. RADIO AMMETERS came with the German apparatus to Annapolis in 1902 and the Navy has used such ammeters in increasing numbers since that time. Commercial organizations were slower to adopt these however. Within the last two years radio ammeters have been used in noticeably increasing numbers in commercial stations.

18. ANTENNA VOLTAGE increased from time to time up to the insulation limits as attempts were made, with different transmitters, to increase the power. The point of breakdown was quickly reached with the plain antenna transmitters, and this was one of the several objectionable features of the plain antenna transmitter. It may be that the insulation broke down more quickly with this type of transmitter because the antenna potential to ground remained high (before the spark discharge took place) for a greater length of time than where coupled circuits were used. For example, assuming that a coupled transmitter produced only alternating currents in the antenna and the potential rose from zero to a maximum and returned to zero again in one millionth of a second, while with the induction coil connected in the plain antenna circuit, the potential possibly increased from zero to a greater maximum for about one-tenth of a second before the discharge took place, the antenna insulation was subjected to higher potential for longer intervals.

19. ANTENNA SIZE. At first the vertical dimension of the

Digitized by Google

antenna was increased because it was recognized quite early that the sending range increased with the height of the antenna.

Later it was recognized that more power could be put in an antenna without breaking down the insulation by adding horizontal wires to the vertical antenna, and more power meant greater range.

Still later the antenna size was also increased to obtain natural periods more nearly equal to the longer transmitting wave lengths desired. An exception was the recent (since 1912) decrease in horizontal length of some shipboard antenna, to bring down the natural period so that the legal requirements for 300 meter waves could be met, as prescribed by the International Radio Conference.

In each step of development of the transmitter the size of the antenna was as a rule increased.

The plain vertical antenna grew from less than 100 feet (30 m.) to over 100 feet in height.

With the tuned coupled circuits at land stations in 1905, the height increased to over 200 feet (60 m.), and the horizontal dimensions were increased by fanning the wires and by increasing the number of masts. On shipboard, wider spreaders and more wires were used, increasing the capacity and *decreasing* the *resistance*.

With the impulse exitation transmitters, the height on land increased to 400 feet (120 m.) or more and the spread became greater; for example, in 1912, Sayville with its antenna, about 500 feet high and covering an area of about 4,000,000 square feet. With the constant amplitude transmitter came still larger antennas, for example, Tuckerton in 1914, with its antenna 850 feet (250 m.) high and covering an area of about 7,000,000 square feet.

An increase in height of about 10 to 1 occurred between 1899 and 1915, and a large increase in area with consequent capacity increase of about 25 to 1.

For future high power stations, right of ways may be obtained along roads or waterways and long antenna erected on high towers in one or more directions from the transmitter.

The single vertical wire antenna probably gave rise to the term "open circuit" while its use as plain antenna helped to stamp radio frequency circuits as "oscillating circuits." Apparently the term "open circuit" is passing with increased horizontal dimensions of antenna as also is "oscillating" with the advent of constant amplitude transmitters.

Digitized by Google

20. SPARK FREQUENCY increased from about 30 to 1,000 sparks per second during the period from 1899 to 1909. At Catalina, in 1902, about 70 sparks per second were used. In 1903, the 60 cycle alternating current brought the spark frequency to 120 or more per second. By 1905, apparently, spark frequencies as high as 500 per second were used. In 1909, spark frequencies of 1,000 per second and higher were used, particularly with quenched gap transmitters.

21. DECREMENT. The decrements of the alternating currents in the antenna have materially decreased since 1899.

Apparently, with practically all the steps in radio development tending to produce longer ranges and greater continuity of radio service, the effective power radiated increased with, and largely because of, the decrease in decrement. Or, probably, it may be said that the trend of transmitter development has been to increase the power and the size of the antenna and to produce single, radio frequency, constant amplitude (zero decrement) alternating current in the antenna.

22. UNIFORM COMMERCIAL APPARATUS. The era of standardization from the standpoint of having apparatus of fixed type was between about 1908 and 1912, with the peak equipment consisted of a power switchboard, motor generator of uniformity in apparatus at about 1910. The uniform (delivering 60 cycle A. C. and about 1 K. W.), open core transformer, rack with 12 jars, muffled open gap in a helix (direct coupled), two coil direct-coupled tuner, carborundum receiver, telephones, and flat top antenna (loop connected). This uniformity kept down first cost and maintenance, but it prevented material improvement, because improvement meant violation of uniformity and consequent raising of maintenance cost and because other vessels would want the same improvement thus resulting in the scrapping of apparatus without indication of sufficient compensation.

23. STOCK JOBBING. The exaggeration of radio matters in connection with the sale of "wireless" stocks of doubtful or practically no value was, as a rule, more or less associated with the operating commercial radio companies, from 1900 to 1911. As early as 1901, one company circulated printed matter and letters emphasizing the increase in telephone and telegraph stations and the great increase in selling price of telephone stocks and implying that the radio telegraph and telephone were ready to take the place of wire telegraph

Digitized by Google

and telephone. This company and subsidiary companies sold or attempted to sell stock. The same general process with amplifications continued to 1911 being promoted by several groups of people and under many names.

This stock jobbing influenced radio development in many ways; and whether or not this method was good, bad, or avoidable it certainly was an effective factor.

To sell stock required the showing of assets and activity. Patents and stations were considered as assets and activity. A patent was usually cheaper than a station which probably accounts for many radio patents.

Stations which were unprofitable from the standpoint of tolls or rental were established and maintained for and by the sale of stock.

Many steamship companies apparently only equipped their vessels with radio some years ago because it cost them little or nothing. By virtue of stock jobbing, the ocean-going public received more radio service and protection some years ago than it probably would have otherwise received, and the science and art were developed thereby. In the main, the general public paid the expenses without return of dividends or principle. It will be noted that curve *L* (land stations) drops at the beginning of the discontinuance of stock jobbing in 1910 and for similar reason the commercial ship stations, curve *S* changed direction in 1912.

Since 1911, the laws requiring and regulating radio have probably been the chief factors in fixing the number of ship and shore stations.

24. Post Office Prosecution. This result of stock jobbing reached its most active stage in 1910 and 1911, or about ten years after the stock jobbing started. About ten men were sent to the penitentiary and two or more were fined. These were later-day stock jobbers, the earlier stock jobbers had been out of radio long enough to be forgotten or to be protected by the statute of limitations before the continued and growing complaint from the public became effective. While the charges and convictions were specified under several counts and certain specific instances were brought up for proof, it possibly may be summed up by saying these men were punished for getting money from widows and poor people by flagrant misrepresentation about radio thru the United States mails.

Digitized by Google

25. STOCK SALES to the public by stock jobbing methods were largely stopped in 1910 and 1911 by the Post Office prosecution; but, oddly enough, probably the greatest sale of radio stocks in the United States history occurred in 1912, when apparently about $6,000,000 changed hands in the sale of Marconi Wireless Telegraph Company of America stocks. The Marconi Company had raised its capitalization for taking over the United Wireless Company. Marconi stock was put on the market following the publicity attached to the Post Office prosecution and then the Titanic sank, further emphasizing radio. The result was old Marconi stocks went up in price from about $12 to $360 per share on the curb market and the new issue was sold.

Apparently some of the results of this new sale of stock to the public were to produce high power stations for trans-oceanic work, increase patent litigation, raise rentals to steamship companies, cause steamship companies to own and operate radio equipments, with some development of steamship apparatus by the Marconi Company.

26. OVERLAND RADIO was attempted in competition with the wire lines at one time or another in a majority of the states of the United States. In many cases the gross receipts were not sufficient to pay for the coal used in heating the stations. A large percentage of these stations were said to have been erected for stock jobbing purposes.

As a rule the overland stations were unable to handle business satisfactorily during the season of summer atmospheric disturbances, and the stations interfered with each other. In addition to this, they were competing with minor portions of two or three long established wire lines that were equipped to render service to nearly any point in the United States and to a great many points thruout the world, and the public was in the habit of using the wire lines. The result was practically universal abandonment of overland radio stations.

27. OPERATING ORGANIZATIONS have apparently varied from about 5 in 1902 to 10 at the present time, marked in earlier days by small short-lived companies, later by larger longer-lived companies with the more recent addition of operation by steamship companies.

28. MANUFACTURING ORGANIZATIONS. For a time, manufacturing companies were usually operating companies, but with the continued demand of the Navy and Army for

Digitized by Google

radio apparatus of U. S. manufacture and for improved apparatus, companies other than operating companies were formed to manufacture, and to meet this demand.

29. VALUE OF RADIO RECOGNIZED. In the earlier history except when convinced by a stock salesman, the public as a whole apparently regarded radio as more or less of a scientific toy which had possibilities but was not particularly useful; and because of stock jobbing, radio people, as a class, bore a somewhat bad reputation, both as to morals and ability.

The sinking of the "Republic" and the use of radio caused the public to recognize that it was of value, and its subsequent use (as, for example, on the S. S. "Ohio," and lastly, with the "Titanic") made such an impression that Congress passed laws requiring and controlling radio.

It may be said that from 1899 to 1911, the period characterized by stock jobbing, was the ERA OF DEVELOPMENT OF DEMAND FOR RADIO SERVICE, and with the coming of the Radio Laws and the stopping of stock jobbing in 1911 began the ERA OF FIXED MINIMUM DEMAND FOR RADIO SERVICE.

30. 50 PASSENGER, OCEAN LAW.

The first law passed, which became effective in July, 1911, required *ocean-going* vessels carrying *passengers* and carrying 50 or more persons, including passengers and crew, for a distance of 200 miles from United States ports to have a radio operator and apparatus capable of working 100 miles (160 km.). Additional stations principally on ships, were required, which offset somewhat the decrease in stations due to the closing of stock jobbing stations.

50 PERSONS LAW

In October, 1912, a revised law became effective for 50 persons which added one more operator and an emergency auxiliary source of power for the radio transmitter on ocean-going passenger ships; and later in 1913 on cargo and passenger carrying ships on the Great Lakes and on ocean cargo ships.

As will be noted in curve *S*, by the time all of these laws became effective the number of ship stations was approximately twice that of 1911 when the first law began to be effective.

In addition, these laws covering vessels carrying 50 persons required two licensed operators and an auxiliary source of power which increased the number of operators on commercial ships

Digitized by Google

to about four times that of 1911 and brought in the plain antenna auxiliary set and later the full power auxiliary set.

The licensing of the operators by examinations raised the technical training of the operators as a class.

The requirement for continual service and operative apparatus has improved the apparatus and provided far better radio protection for occasions of distress on vessels.

33. The DECREMENT LAW, or portion of the law, effective in 1912 with regulations, was made to prevent interference and for that reason required certain wave lengths and licenses for various classes of stations, all of which stations were required to use a decrement of less than 0.2.

34. FULL POWER AUXILIARY. This is an auxiliary source of power capable of furnishing sufficient power to operate the main radio transmitter for four hours or more. Two such installations were made early in 1911 by the United Wireless on the Lamport and Holt line. When the law requiring auxiliary sources of power went into effect, ten inch induction coils with small storage battery were put on by the Marconi Company, thereby providing less power for distress purposes than was provided for ordinary business. In 1913, the United Fruit Company installed large Edison storage batteries to furnish full power for their main transmitters and for emergency deck lights, and since then other steamship companies have been making somewhat similar installations.

35. PATENT LITIGATION. In August, 1902, the Marconi Wireless Telegraph Company of America brought suit against the de Forest Wireless Telegraph Company on the Marconi reissue patent number 11,913. Nearly three years later, in April, 1905, Judge Townsend held that claims 3 and 5 of the Marconi patent were infringed and granted an injunction and accounting on those claims, but said that claim 1 was too broad and claims 8, 10, and 24 were not infringed. However, in April, 1905, the de Forest Wireless Telegraph Company was a company of the past, and the decision practically only served to make others wary of claims 3 and 5. So that, altho the Marconi Company sued the American de Forest Wireless Telegraph Company in March, 1906 on claim 3 of this patent, the American de Forest Wireless Telegraph Company was using the loop antenna, and Judge Townsend rendered a decision in April, 1907, holding that the showing

Digitized by Google

made did not warrant the granting of an injunction. The chief result of this litigation which started in 1902 and ended in 1907, was the loop antenna, excepting, of course, that a considerable sum of money was probably expended. Taking into account all the radio litigation up to the present, probably the main features have been the expenditure of money and the time between the starting of the case and the final decision. This litigation effected the development of radio in a number of ways.

Beginning with 1902, one or more suits have been before the courts each year.

The decision in favor of the Marconi Company, plaintiffs, in 1905 resulted in the loop antenna which was successfully defended later.

The decision in favor of Fessenden and his associates, plaintiffs, in 1906 on the electrolytic detector, helped bring crystal detectors into use.

The decision in favor of the Marconi Company, plaintiff, in 1914, against the National Electric Signaling Company, and the National Electric Signaling Company suits against the Marconi Company apparently brought about the working agreement between these companies.

Seven suits filed in 1914 were the greatest number filed in one year.

Of approximately 27 suits filed from 1902 to the present time, apparently only seven have shown permanent status in favor of the plaintiff.

Of these, two were rendered ineffective by the defendant subsequently using other apparatus, two produced a working agreement, one was in connection with the selling out of the defendant, and the other two partially restricted two companies but are still being fought.

About eight suits are pending trial or decision.

Apparently United States radio patent litigation has been unprofitable for both the defendants and plaintiffs.

The time elapsed between filing the suit and the decision has varied from one month to four years and averaged about one and one half years.

36. Operation By Steamship Companies. That is, wherein the steamship companies rent or buy their apparatus, handle the traffic accounts, control their operators the same as the other members of their crews, etc. Among the first to do this was the United Fruit Company. Recently this

Digitized by Google

method of operation has increased quite rapidly, particularly on the Pacific Coast.

In the early days the stock jobbing operating companies rented the operators, apparatus, and traffic service for from $62.50 per month *down* to *nothing* per month. The steamship companies were not required to have it, and they were *not responsible* for it. Then, to the steamship company it was largely a *cheap* novelty which might be useful.

But with the departure of the low rent stock jobbing method, and the coming of some patent decisions and combinations in attempted patent monopoly, and the enforcement of radio laws, conditions have changed. Now, to the steamship company, it is more expensive and usually it is a *necessity* and a *responsibility*.

It has become a matter of question whether the steamship company cannot operate radio as cheaply as to rent its operation, and since it is now a *necessity* and a *responsibility*, the natural question is, why should not radio apparatus be in the same business system as other parts of the ship's equipment, the operator the same as any other member of the crew, and the traffic accounts the same as other traffic pertaining to ships? The result is that additional lines own and control the radio on their vessels.

37. THE INSTITUTE OF RADIO ENGINEERS. The Institute of Radio Engineers, formed by the combining of the Society of Wireless Telegraph Engineers and the Wireless Institute, was developed in the former organizations, principally by the persistent efforts of a few individuals. Practically, its early development was mainly characterized by the persistence of a few persons in meeting, reading, and discussing radio papers, regardless of attendance. Later, gradually, and still later, more rapidly, others became interested and active until now The Institute of Radio Engineers is an international, influential, educational organization, occupying a class by itself, and is worthy of classification as an effective factor in radio development.*

SUMMARY: The history of radio development in the United States is considered in great detail. Transmitters, detectors, antennas, a number of detailed parts of radio apparatus, and various branches of radio communication are classified, and their progress studied. Such topics as standardization, financial procedure, litigation, radio laws, and their consequences are treated fully.

---

* In this connection, it is a pleasure to inform the readers of the PROCEEDINGS that it is largely thru the loyal and continued efforts of Mr. Marriott that the originally very restricted membership of the Institute now runs into the thousands.—EDITOR.

Digitized by Google

Lloyd Espenchied: Mr. Marriott's paper is the story of the development of a new communication art, from the time of its inception, thru a varied probationary career up to a period in which it has become established upon a substantial service basis.

The value of the paper is considerably enhanced by the data given and by the manner in which it is graphically presented. This not only adds to its usefulness as an historical reference, but also injects an element of engineering importance, by showing up existing trends in the art and thereby enabling, by imaginary extrapolations of the curves, some insight to be had into the future.

As regards the trend in the technique of the art, the author's first chart illustrating the history of the development of transmitters, indicates clearly the tendency toward types giving a more and more frequent renewal of the antenna energy, i. e., toward the constant amplitude type of transmitter. The most intermittent type of transmitter (plain antenna) is already declining in numbers, while the next most intermittent type (ordinary coupled tuned circuit type) seems to have reached its growth and to have about started upon its decline. The impulse excitation type of transmitter representing the third step toward the constant amplitude type has taken up practically all of the growth of the more recent years and seems still to be growing. Altho the growth of the constant amplitude type has been slow up to the present, nevertheless from the trend indicated in the chart, and from our knowledge of its desirable transmission characteristics, we would be led to expect henceforth a more rapid growth in the number of such transmitters, in time accompanied by an actual decrease in the number of stations of other types.

Somewhat analogous trends are shown in the history of detector developments, starting as it does with the intermittently operated coherer, which accompanied the most intermittent type of transmitter, and coming down to the vacuum-tube-beat type of detector, co-operating with transmitters of the constant amplitude type.

Turning now to the curves of chart 2 showing the growth in the application of the radio art, we naturally wonder as to whether, for instance, the total number of stations will continue to grow at the same rate as in the past or whether it is approaching

Digitized by Google

the "saturation" point. Curve T, giving the total number of radio stations in the United States, shows a rapid rise for the last six or seven years. This curve is made up in greater part by ship stations, and the recent growth in such stations is very largely due to legislative enactment compelling their adoption. This has resulted in the rapid discounting of a growth which probably would have occurred naturally, tho more slowly, by the gradual recognition of the value of radio to the maritime world. Hence there is some question as to whether, in so far as it is due to ship stations, curve T may not soon fall off to a growth coincident with that of the maritime field itself. However, as regards total growth in an art as young as is radio, one should not lose sight of the possibility of enlargements in its sphere of economic utility brought about by scientific or technical advances either in it or in other arts as, for instance, that of aerial navigation.

February 15, 1917.

Digitized by Google

THE NEW YORK
PUBLIC LIBRARY
ASTOR
TILDEN

Digitized by Google

ON THE USE OF CONSTANT POTENTIAL GENERATORS FOR CHARGING RADIO TELEGRAPHIC CONDENSERS AND THE NEW RADIO TELEGRAPHIC INSTALLATIONS OF THE POSTAL AND TELEGRAPH DEPARTMENT OF FRANCE*

By

LEON BOUTHILLON

(ENGINEER IN CHARGE OF THE RADIO TELEGRAPHIC SERVICE OF THE POSTAL AND TELEGRAPH DEPARTMENT OF FRANCE)

Numerous experimenters have attempted to use constant electromotive forces for charging the condensers used in radio telegraphy. Even if we neglect the field of sustained waves, such as are produced by the arc (of Poulsen, de Forest, Blondel, etc.), by the method of Galletti, or by the method of Marconi, and restrict ourselves to spark radio telegraphy, we find that there have been numerous attempts to use constant electromotive forces. Limiting ourselves to the principal instances, we recall at once that Marconi employed in his stations at Clifden and Glace Bay sets of 6,000 cells of storage battery. This battery was charged by means of direct current generators. When it was used alone, the voltage was from 11,000 to 12,000; but when the battery was used in parallel with the generator, the potential difference could be raised to 15,000 volts. The discharger consisted of a disc on the periphery of which were a number of regularly spaced projections, which disc rotated between two smooth electrodes. The arrangement of the circuits is shown in Figure 1.† In collaboration with Captain Brenot, Blondel carried on a series of experiments directed toward radio telephony at the Eiffel Tower. He used a direct current machine with considerable inductance in the charging circuit of the condenser, and a stationary spark gap.

Von Lepel introduced a system whereby the musical note was obtained thru the effect produced by an auxiliary circuit consisting of inductance and capacity connected in parallel with the

* Received by the Institute, March 19, 1916. Translated from the French by the Editor.

† See "Proc. Royal Institution," June 2, 1911.

Digitized by Google

gap, as indicated in Figure 2. In this figure, *S* is the key, *G*, *G* the choke coils, *H* an inductance, *F* a condenser, *A* the gap, and *C*, *D* the radio frequency coupler. (See "Electrical Engineering," September 15, 1911, page 591). Related to this system are the experiments in multiplex radio telegraphy carried on by the Compagnie Générale de Radiotélégraphie, wherein circuits indicated in Figure 3 were used. (See G. E. Petit and L. Bouthillon, "La Telegraphie sans Fil," 3rd edition, page 69. Delagrave, Paris.)

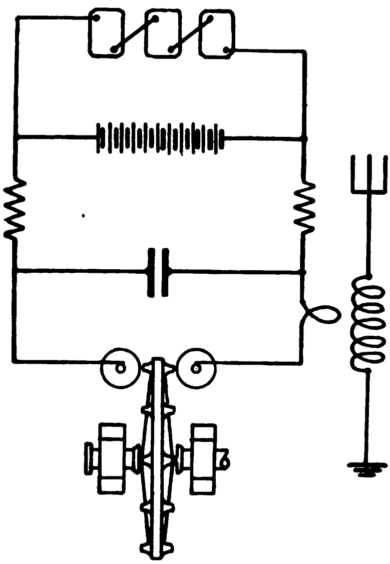


FIGURE 1—Marconi High Direct Voltage Transmitter

The present paper will show why, when faced with the task of developing a type of radio telegraphic station for the Postal and Telegraph Department of France, I also have chosen to use constant electromotive forces for charging the condensers; and also how, by selecting the best features of the systems of Marconi and Blondel, I have formed a combination which is an advance on each of them.

I shall begin by studying completely the functioning of a charging circuit connected to a source of constant electromotive force and of a discharge circuit containing a gap. I shall then discuss the relative value of the various types of generators and indicate the criteria of their suitability in radio telegraphy.

Digitized by Google

In the third part of the paper, I shall indicate the principal characteristics of the system selected. In the fourth part of the paper, the choice of system will be justified by comparing its characteristics with those of the usual alternating current system.

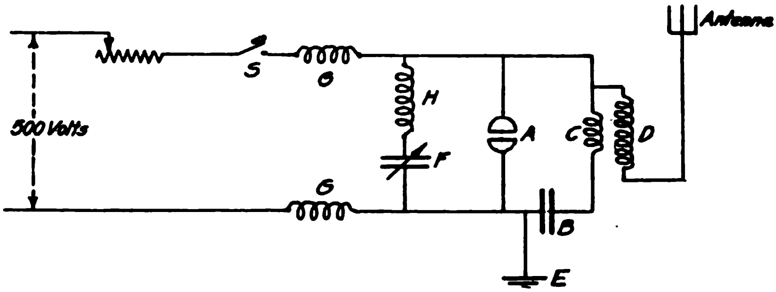


FIGURE 2—LEPEL CIRCUIT

PART I. THE CHARGING OF CONDENSERS BY CONSTANT ELECTROMOTIVE FORCES AND THEIR DISCHARGE IN OSCILLATORY CIRCUITS. PRODUCTION OF MUSICAL TONES.

1. *General Principles.* We are concerned, in all system of spark radio telegraphy, with the charging of condensers by a high potential generator and their subsequent discharge in an oscillatory circuit, the sequence of phenomena being repeated a certain number of times per second, which number determines the pitch of the characteristic signal note. This note is musical if the discharges recur sufficiently rapidly and regularly.

The arrangement to which we refer is shown in Figure 4. The charging circuit contains a constant potential generator S' of voltage E, an inductance L, a resistance R, a capacity C, and a discharger D in the oscillatory circuit. The sequence of effects depends on whether the gap D is rotary or stationary. In the latter case, a spark passes and the condenser is discharged each time the potential difference at its terminals reaches the constant value V, which value is determined by the break-down distance. In the former case, the spark passes at regular intervals separated by a time τ, which corresponds to the time between the passage of successive studs on the rotary electrode.

In both cases, we suppose that the duration of the spark is negligible compared to the charging time. We shall also suppose

Digitized by Google

that the condenser is completely discharged at the termination of the spark. These assumptions are practically correct. In connection with the study of the action of this circuit the following theory is necessary.

2. *Theory of the Charging of a Condenser by a Constant Potential Generator.* In Figure 5, let the constants be as indicated.

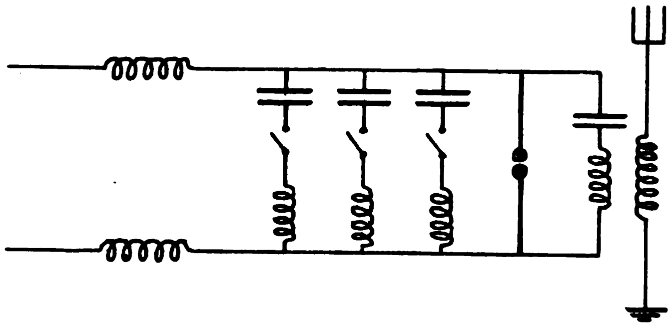


FIGURE 3—Multiplex Transmitter Compagnie Générale de Radiotélégraphie

Suppose that at time t, the current is i, the potential difference of the condenser terminals v, and the charge of the condenser q. The differential equation of the circuit is

$$L\frac{d^2 q}{d t^2} + R\frac{d q}{d t} + \frac{q}{C} = E \tag{1}$$

This merely expresses the equality at all times of the E.M.F. E and the sum of the potential differences across L, R, and C. In addition, at all times,

$$v = \frac{q}{C} \quad \text{and} \quad i = \frac{d q}{d t} \tag{2}$$

The condenser being supposed to be completely discharged when the spark ceases, the potential difference is zero at the beginning of the charge. Let i_o' be the corresponding current. The solution of (1) takes three different forms, according as the expression

$$\frac{1}{CL} - \frac{R^2}{4L^2}$$

is positive, negative, or zero. The only case which is interesting in practice (since it is the only case wherein an appreciable output can be obtained) occurs when the expression given above

Digitized by Google

is positive. In this case, the current and potential difference at the condenser terminals are the following:

$$\left.\begin{aligned} i &= \frac{E}{L\omega}\varepsilon^{-at}\sin\omega t + i_o'\frac{\cos(\omega t+\phi)}{\cos\phi}\varepsilon^{-at} \\ &= i_o'\varepsilon^{-at}\frac{\sin(\omega t+\mu)}{\sin\mu} \\ v &= E\left[1-\varepsilon^{-at}\frac{\cos(\omega t-\phi)}{\cos\phi}\right] + L\omega i_o'\frac{\sin\omega t}{\cos^2\phi}\varepsilon^{-at} \\ &= E - i_o' L\omega\frac{\cos(\omega t+\mu-\phi)}{\sin\mu\cos\phi}\varepsilon^{-at} \end{aligned}\right\} \tag{7}$$

where we call,

$$a=\frac{R}{2L}, \qquad \omega=\sqrt{\frac{1}{CL}-\frac{R^2}{4L^2}},$$

$$\frac{a}{\omega}=\tan\phi, \qquad \frac{L\omega i_o'}{E-Lai_o'}=\tan\mu \tag{8}$$

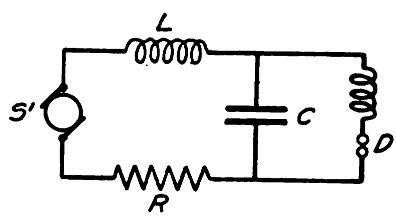


FIGURE 4—Charging Circuit and Discharge Circuit

Both current and potential difference are periodically damped. The period is $T=\frac{2\pi}{\omega}$ and the logarithmic decrement is $\delta=aT$. The potential difference, which was zero at the beginning of charge, is represented by a periodically damped oscillation curve, crossing the axis of co-ordinates E at regular intervals. It has its maxima when

$$\omega t=(2k+1)\pi-\mu, \tag{9}$$

and its minima when

$$\omega t=2k\pi-\mu. \tag{10}$$

The location of the maxima and minima is given by

$$\frac{V}{E}=1\pm\frac{L\omega i_o'}{E\sin\mu}\varepsilon^{-at}. \tag{11}$$

Digitized by Google

The entire family of curves which show the values of the potential difference corresponding to different values of i_o' have a series of common points defined by the relations

$$\omega t = (2k+1)\pi$$
$$v = E\left(1 + \varepsilon^{-a(2k+1)\pi}\right) \tag{12}$$

and

$$\omega t = 2k\pi$$
$$v = E\left(1 - \varepsilon^{-a.2k\pi}\right), \tag{13}$$

these being the curves 1, 2, and 3 of Figure 6.

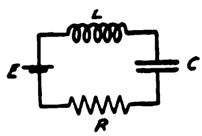


FIGURE 5—Charging Circuit

The current, which is i_o' at the beginning of the charge, is represented by a periodically damped curve, oscillating from one side to the other of the time axis, as shown in curves 1, 2, and 3 of Figure 7.

The zeros correspond to the maxima and minima of the difference of potential:

$$\omega t = k\pi - \mu \tag{14}$$

These maxima and minima occur at times given by the formula

$$\omega t = (2k+1)\frac{\pi}{2} - \mu - \phi. \tag{15}$$

Efficiency of the Charging Circuit. Let us suppose that the spark passes at the time when the potential difference at the condenser terminals is v. The energy available for the circuit at the condenser terminals is $\frac{1}{2}\,Cv^2$. The energy expended in the charging circuit is $\int_o^t E\,i\,dt$. The efficiency is the ratio of these two quantities:

$$\gamma = \frac{\frac{1}{2}Cv^2}{\int_o^t E\,i\,dt} = \frac{1}{2}\,\frac{vq}{E\int_o^t i\,dt} = \frac{1}{2}\,\frac{vq}{Eq} = \frac{1}{2}\,\frac{v}{E}. \tag{16}$$

Digitized by Google

In the case of aperiodic charging, the potential difference at the condenser terminals is always less than the electromotive force and the efficiency less than 0.5. Because of this low value of the efficiency, such a condition should be avoided in practice. In the case of "periodic charging," the potential difference is a damped period function, oscillating above and below the electromotive force E. Its maxima are given by

$$\omega t=(2k+1)\pi-\mu, \tag{17}$$

which maxima become smaller as k increases. (See the curves of Figure 6.)

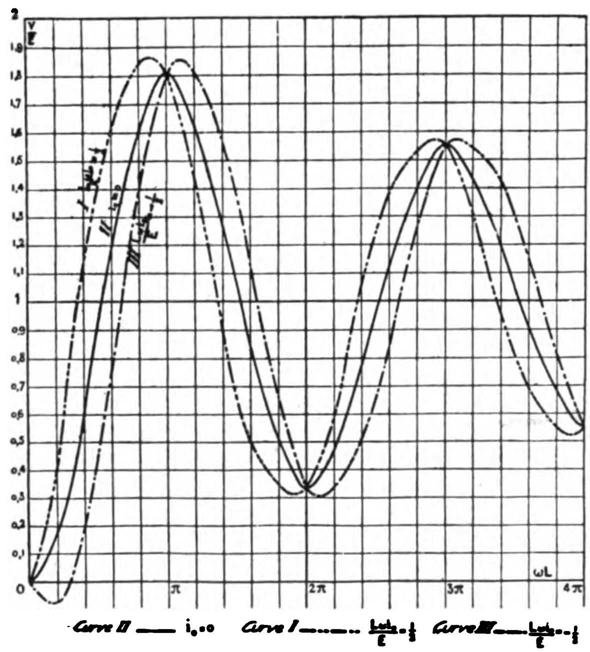


FIGURE 6—Variation of Condenser Terminal Voltage as Function of Charging Time $t \cdot (\delta=0.4)$

3. *Study of the Production of Musical Tones: Characteristic Conditions.*

The charges and discharges will take place in such a way as to produce a musical note by the successive sparks if the two following conditions are met:

1. That the successive condenser discharges are regularly

Digitized by Google

spaced, at equal intervals, and consequently that successive charges require the same constant time.

2. That the voltage v and the current i are the same at the beginning of each charge. The voltage being zero, if the discharge is supposed to be complete at the time that the spark ceases, it is only necessary that the current i' shall have the same value i_o at the beginning of each charge. Since it is also assumed

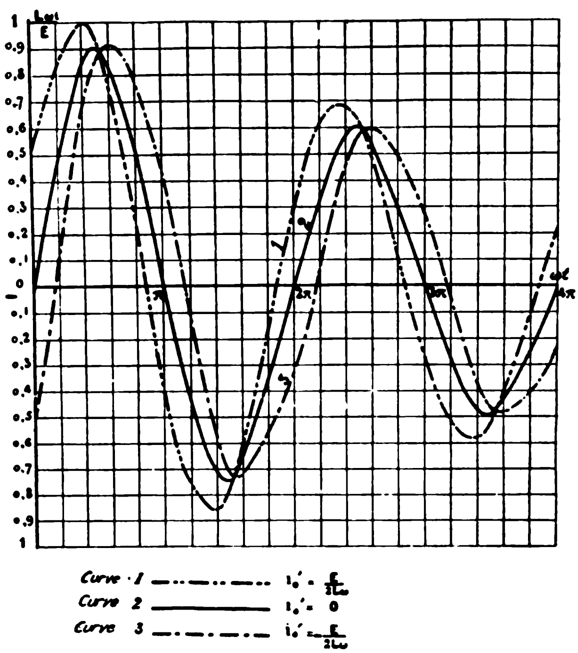


FIGURE 7—Condenser Charging by Constant E. M. F.
Current in Charging Circuit

that the time of discharge is negligible in comparison with that of charging, the current in the charging circuit must remain constant during the entire discharge, and the condition (2) above may be expressed as follows: The current at the end of the discharge must be equal to the initial current.

When applied to equations (7) and (8), these conditions lead to the following relating between the charging time τ and the current i_o for any spark.

$$i_o\left[1-\varepsilon^{-a\tau}\frac{\cos\left(\omega\tau+\phi\right)}{\cos\phi}\right]=\frac{E}{L\,\omega}\,\varepsilon^{-a\tau}\sin\omega\tau, \qquad (18)$$

Digitized by Google

We obtain also for the potential difference at the end of the charging period, under conditions of a musical note of frequency $\frac{1}{\tau}$,

$$V=E\left\{1-\varepsilon^{-a\tau}\frac{\cos(\omega\tau-\phi)}{\cos\phi}+\varepsilon^{-2a\tau}\frac{\sin^2\omega\tau}{\cos^2\phi\left[1-\varepsilon^{-a\tau}\frac{\cos(\omega\tau+\phi)}{\cos\phi}\right]}\right\}$$

$$=\frac{E\left(1-2\,\varepsilon^{-a\tau}\cos\omega t+\varepsilon^{-2a\tau}\right)}{1-\varepsilon^{-a\tau}\frac{\cos(\omega\tau+\phi)}{\cos\phi}} \tag{19}$$

Consequently, corresponding to each value of V, the sparking potential difference which is supposed to be held constant (as in the case of a stationary gap), there is a condition of musical tone production identified with the smallest value of τ given by equation (19) and by the value of i_o thereafter deduced from equation (18). So that, the value of V remaining constant, the current is i_o at the beginning of the first spark, and all sparks thereafter come at a regular interval τ thus giving rise to a musical tone.

In the same way, corresponding to each value τ of the time of charge, supposed to be held constant (case of the rotary gap), there is a production of a musical tone identified by the values of V and i_o. If the current at the beginning of the first spark is i_o, all later sparks will be produced by the same potential difference.

Sparking Potential and Efficiency.

The sparking potential and the efficiency which is proportional to it each vary with the frequency of the musical tone. Whenever the time of charge τ, which is also the period of the musical tone, is not zero, there are a series of maxima for values of τ corresponding to zero values of the derivative $\frac{dv}{d\tau}$.

$$\frac{dv}{d\tau}=\frac{E}{CL\omega}\cdot\frac{\sin\omega\tau\cdot\varepsilon^{-a\tau}\left(1-\varepsilon^{-2a\tau}\right)}{\left[1-\varepsilon^{-a\tau}\frac{\cos(\omega\tau+\phi)}{\cos\phi}\right]^2} \tag{20}$$

The maxima occur when

$$\omega\tau=(2k+1)\pi \quad\text{or}\quad \tau=\frac{(2k+1)\,T}{2} \tag{21}$$

That is, the maxima occur when the time of charging is an odd multiple of the half period of the charging oscillation.

Digitized by Google

The minima occur when

$$\omega\tau = 2k\pi \text{ or } \tau = kT, \tag{22}$$

that is, for values of the charging time which are multiples of the entire period of the charging oscillation.

The greatest of all the maxima is when

$$\tau = \frac{T}{2} \tag{23}$$

which is the case of a musical tone produced by one spark per half period. The current is then zero at the beginning and at the end of each charge, and the sparking potential is

$$V = E\left(1 + \varepsilon^{-\frac{\delta}{2}}\right) \tag{24}$$

and the efficiency is

$$\gamma = \frac{1 + \varepsilon^{-\frac{\delta}{2}}}{2} \tag{25}$$

These conditions then are those of maximum efficiency with a musical tone. The efficiency is greater the less the logarithmic decrement of the charging oscillation. When the decrement becomes zero, the efficiency is unity.

We shall successively study the variation of the maximum efficiency with the damping of the charging circuit and the variation of the efficiency when t changes slowly at values near $\frac{T}{2}$.

The following table gives the values of the maximum efficiency corresponding to various values of the decrement.

Decrement of Charging Circuit	Efficiency	Decrement of Charging Circuit	Efficiency
0.0	1.00	0.8	0.84
0.2	0.95	1.0	0.80
0.4	0.91	2.0	0.68
0.6	0.87		

The maximum efficiency is obtained at a spark frequency double that of the oscillations of the charge, i. e., one spark per half period. It is interesting to note how the efficiency changes when the spark frequency differs from this most desirable value $(\omega\tau = \pi)$.

If we assume $\frac{\alpha^2}{\omega^2}$ to be negligible compared to unity, the potential difference reduces to $V = 2E$ and the efficiency to

Digitized by Google

$\gamma = 1$. In this case, the efficiency will always be equal to unity no matter what the period of the musical tone.

In practice, it is impossible to eliminate the resistance of the charging circuit; but the curve of sparking potential has the shape of curves I, II, and III of Figure 8 with large flat regions in the neighbourhood of the maxima. Consequently, considerable

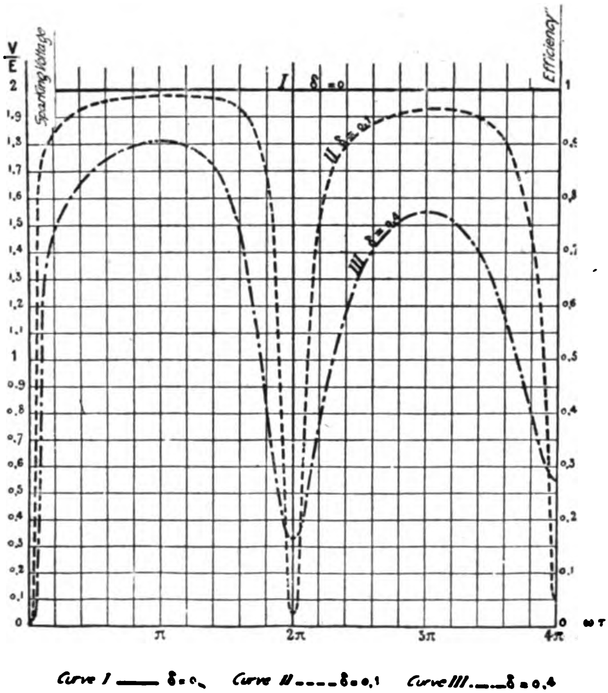


Figure 8—Variation of Sparking Voltage and Efficiency as Function of Period τ of Musical Note

variations in the time of charging produce only slight changes in the efficiency. The less the decrement, the smaller are these changes and the nearer the maximum efficiency approaches unity.

The curves of Figure 8 show the variations of potential difference at the condenser terminals or of the efficiency as a function of the period τ of the musical tone for the three values of the logarithmic decrement, namely: $\delta = 0$, $\delta = 0.1$, and $\delta = 0.4$.

It can be seen that the spark frequency may be multiplied

Digitized by Google

by 3 in the case where $\delta = 0.4$ (a value rarely exceeded in practice) and by 7 in the case where $\delta = 0.1$ without diminishing the efficiency by more than 10 per cent. This is an interesting characteristic of methods of charging continuous by sources of direct current.

Initial Current. The relation between τ the time of charge and the initial current i_o (which is also the current at the moment of discharge) is the following:

$$L \omega i_o = E \frac{\sin \omega\tau \; \varepsilon^{-a\tau}}{1 - \varepsilon^{-a\tau} \dfrac{\cos(\omega\tau + \phi)}{\cos \phi}}$$

For $\tau = 0$
$$L \omega i_o = \frac{E \omega}{a} \qquad i_o = \frac{E}{L a}$$

Thereafter i_o decreases, reaching zero when $\omega \tau = k \pi$.
It assumes the general shape of a damped periodic curve of period

$$T = \frac{2\pi}{\omega},$$

and passes thru a series of maxima and minima when

$$\varepsilon^{a\tau} = \frac{\cos(\omega\tau + \phi)}{\cos \phi},$$

which are represented in the curves of Figure 9.

If $a = 0$, that is, if the charging current is without damping, we have

$$L \omega i_o = E \cot g \frac{\omega \tau}{2}. \tag{26}$$

In this case, i is zero when $\omega \tau = (2k+1)\pi$ and infinite when $\omega \tau = 2k\pi$ (curve 1 of Figure 9).

The current i_o assumes the value zero at points corresponding to the maximum sparking potential difference or maxima of the efficiency. The curves of Figure 9 show the variation of i_o as a function of τ for the three values, $\delta = 0$, $\delta = 0.1$, and $\delta = 0.4$. It will be seen that the larger the damping, the smaller i_o.

Potential Difference at the Condenser Terminals during the Charge.

During the charge, the potential difference is given by equation (7) above. The curve representing v is periodic and damped. If there is no sparking, it passes thru a series of maxima given by equation (11) above with the positive sign chosen in the second member, when

$$\omega t = (2k+1)\pi - \mu,$$

Digitized by Google

and thru a series of minima or negative maxima given by equation (11) above with the negative sign chosen in the second member when

$\omega t = 2 k \pi - \mu$ (See the curves of Figure 6).

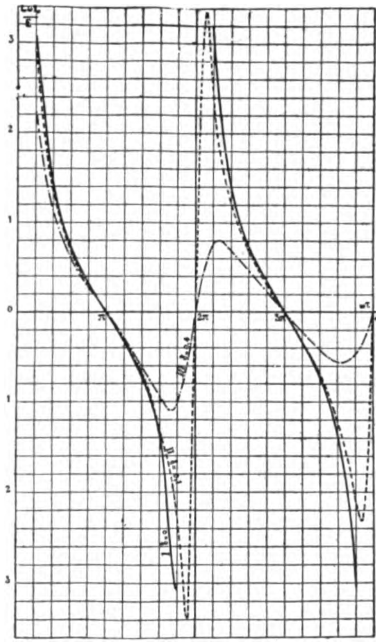


Figure 9—Variation of Initial Charging Current i_0 as Function of Period of Musical Note

If i_0 is positive, the first of all these maxima is always a positive one and the greatest of them all, having the value

$$V_1 = E\left(1 + \frac{L \omega i_o}{E \sin \mu} \varepsilon^{-a t_1}\right) \tag{27}$$

where $\omega t_1 = \pi - \mu$.

If i_o is negative, the first of all the maxima is negative and equal to the expression just given except that the negative sign appears in the second member instead of the positive, and that t_1 is given by $\omega t_1 = -\mu$.

The second maximum is positive, and equal to the expression given in equation (27)
where $\omega t_1 = \pi - \mu$.

Digitized by Google

The greatest of the maxima is the first positive one, V_1. For certain values of i_o and small dampings, it reaches large values.

But this expression does not give the maximum potential difference attained during the entire charging process unless the time of charging τ (which is the period of the musical tone) is greater than half the period of the charging oscillation ($\omega\tau>\pi$). For in this case t_1 is smaller than τ, and the spark takes place before the maximum value is reached. If, on the other hand, the time of charging is less than half the period of the charging oscillation ($\omega\tau<\pi$), the spark takes place before the maximum potential difference is reached, and the greatest potential difference at the condenser terminals takes place at sparking.

Figure 10 shows the changes in the maximum potential difference at the condenser terminals during the charge as a function of the period τ of the musical note, and for three values of the damping decrement:

$$\delta=0, \quad \delta=0.1, \quad \text{and } \delta=0.4.$$

Whenever $\omega\tau$ is less than π, these curves are the same as those which give the sparking potential difference (Figure 9); and when τ is greater than the limiting value mentioned, the curves represent equation (27). It will be noticed that with $\delta=0.1$ and certain values of τ, the condenser terminal voltage is more than four times the generator electromotive force.

Potential Difference at the Inductance Terminals during the Charge.

During charging, the potential difference at the inductance terminals is

$$u=L\frac{di}{dt}=L\,\omega\,i_o\frac{\cos(\omega t+\mu+\phi)}{\sin\mu\cos\phi}\,\varepsilon^{-at}$$

which passes thru a series of maxima when

$$\omega t=2k\pi-\mu-2\phi$$

and minima when

$$\omega t=(2k+1)\pi-\mu-2\phi.$$

If i_o is positive, the first of these maxima is the greatest of all, and has the value

$$V_2=\frac{L\,\omega\,i_o}{\sin\mu}\,\varepsilon^{-at_2}$$

where $$\omega t_2=\pi-\mu-2\phi.$$

If i_o is negative, the first of all these maxima is the greatest, and positive, having the value

$$V_2'=\frac{L\,\omega\,i_o}{\sin\mu}\,\varepsilon^{-at_2}$$

Digitized by Google

where $$\omega t_2' = -\mu - 2\phi.$$

When the damping is not large, which is generally the case in practice, the values of V_1 and V_2' are quite close to the maximum condenser terminal, potential difference diminished by E.

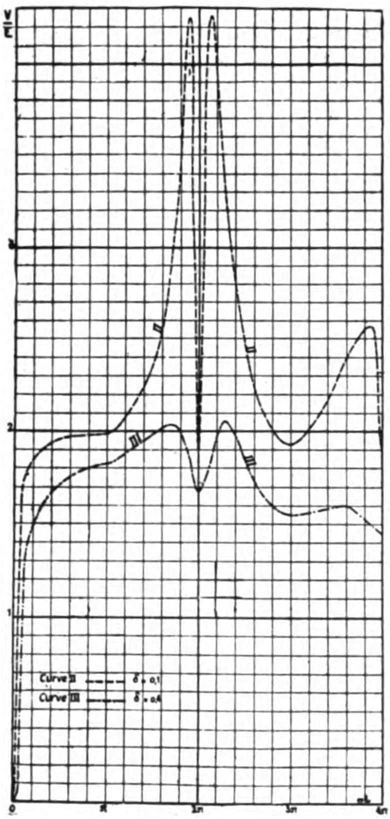


FIGURE 10—Variation of Maximum Voltage at Condenser Terminals during Charging as Function of Period of Musical Note

Difference of Potential at the Resistance Terminals during the Charge.

The value of this potential difference is

$$u = R i = 2 L a i \text{ or}$$

$$u = 2 L a i_0 \varepsilon^{-at} \frac{\sin(\omega t + \mu)}{\sin \mu}$$

Digitized by Google

Average Current in the Charging Circuit. The average current in the charging circuit (which is of interest, as we shall see later, since it is directly proportional to the power expended) is given by

$$i_{av} = \frac{1}{\tau}\int_0^\tau i\,d\,t = \frac{1}{\tau}C\,V = n\,C\,V$$

It is zero for $\tau = 0$, and increases as a function of τ, passing thru a maximum when

$$C\frac{d\,v}{d\,t} = i_{av}$$

and decreasing thereafter.

Energy Expended in the Charging Circuit.

The energy expended during a charge is

$$E\int_0^\tau i\,d\,t = E\,C\,V.$$

If the musical tone produced corresponds to n charges per second, the power expended is

$$W_d = n\,C\,E\,V = E\,i_{av}. \tag{36}$$

It is proportional to the average current, and like it, passes thru a maximum when

$$i_{av} = C\frac{d\,v}{d\,t}.$$

Energy Available at the Condenser Terminals.

This is equal to

$$W_u = \frac{1}{2}n\,C\,V^2. \tag{37}$$

It is zero when $t = 0$ and increases with t, reaching a maximum when

$$i_{av} = 2\,C\frac{d\,v}{d\,t}$$

and diminishing thereafter as t continues to increase.

Inception and Stability of Tone Phenomena:

We have seen that for each value of the sparking potential difference, V, supposed constant (which is the case for a stationary gap), there exists a musical spark determined by the values of τ and i_o. If the value of V is held constant, the current is i_o at the beginning of the first spark. All the successive sparks follow at regular intervals of time equal to the charging time, τ.

Digitized by Google

In the same way, to each value τ of the time of charge assumed constant (which is the case for a rotary gap), there is a musical spark determined by the values of V and i_o. If the current at the beginning of the first spark is i_o, all successive sparks will occur for the same difference of potential V.

It remains to be considered whether the tone phenomena are stable. That is, we must consider whether such musical functioning is re-established after the removal of a temporary disturbance which has caused irregularities, and whether the tone phenomena will occur no matter what the value of the initial charging current i_o'. There is, in fact, no certainty that otherwise the initial current can be regulated in such a way as to be equal to the value i_o which corresponds to a musical note.

From this point of view we shall study the phenomena which take place with each type of discharger.

Case of the Rotary Gap. The time of charging after each spark has the same value τ. Let i_o' be the current at the beginning of the first charge, i_1' that at the beginning of the second charge (which is equal to the current at the end of the first charge), i_2' that at the beginning of the third charge (and equal to that at the end of the second), and so on.

All charging times have the same value τ, the values of i_o', i_1', i_2' . . . i_n' are connected by the following relations, based onequation (7):

$$i_1' = \frac{E}{L\omega}\,\varepsilon^{-a\tau}\sin\omega\tau + i_o'\,\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}$$

$$i_2' = \frac{E}{L\omega}\,\varepsilon^{-a\tau}\sin\omega\tau + i_1'\,\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}$$

. . . .

$$i_n' = \frac{E}{L\omega}\,\varepsilon^{-a\tau}\sin\omega\tau + i_{n-1}'\,\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi} \qquad (38)$$

Let us multiply the first equation by

$$\left[\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right]^{n-1},$$

the second by

$$\left[\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right]^{n-2},$$

and so on, to the (n-I) st, and then add. The terms containing i_{n-1}', i_{n-2}' . . . i_1' disappear, and there remains

Digitized by Google

$$i_n' = \frac{E}{L\omega}\varepsilon^{-a\tau}\sin\omega\tau\left[1+\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}+\ \cdot\ \cdot\ \cdot\right.$$
$$\left.+\left(\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right)^{n-1}\right]+i_o'\left(\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right)^n \tag{39}$$

The series in brackets equals

$$\frac{1-\left[\dfrac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right]^n}{1-\dfrac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}}$$

so that we obtain for i_n'

$$i_n' = \frac{E}{L\omega}\sin\omega\tau\,\frac{1}{1-\dfrac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}}\left\{1-\left[\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right]^n\right\}$$
$$+i_o'\left[\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right]^n$$

or

$$i_n' = \frac{E}{L\omega}\varepsilon^{-a\tau}\sin\omega\tau\,\frac{1}{1-\dfrac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}} \tag{40}$$
$$+\left[\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right]^n\left\{i_o'-\frac{E}{L\omega}\varepsilon^{-a\tau}\sin\omega\tau\,\frac{1}{1-\dfrac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}}\right\}$$

The initial current i_n' for the $(n+1)$st charge contains one constant term, and an additional term which is a function of n, this latter term becoming zero as n increases indefinitely, since

$$\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}$$

is less than 1 regardless of the value of τ.

If the current at the beginning of the first charge has the value

$$i_o' = \frac{E}{L\omega}\varepsilon^{-a\tau}\sin\omega\tau\,\frac{1}{1-\dfrac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}},$$

(that is, the value corresponding to i_o of tone phenomena) the additional term is zero, and the musical note is established after the first spark.

If the time of charge is such that

$$\cos(\omega\tau+\phi)=0,$$

that is,

$$\omega\tau=(2k+1)\frac{\pi}{2}-\phi,$$

Digitized by Google

the additional term is still zero, and the tone phenomena are established at the end of the first charge no matter what value the current has at the beginning of that discharge.

In general, the term

$$\frac{\varepsilon^{-a\tau} \cos(\omega\tau+\phi)}{\cos\phi}$$

is not zero, but it is always smaller than unity and consequently the $(n+1)$st power thereof approaches zero as n increases indefinitely. After a certain number of discharges, which number will be smaller the larger the damping constant a, the additional term becomes negligible. The initial current will then be the same for each discharge, and the musical tone will persist. We find, as must naturally be the case, that the limiting value of i_n' then becomes i_o, which corresponds to musical phenomena having a charging time τ.

Consequently in the case of a rotary gap, tone phenomena are stable. They occur automatically regardless of the current value at the beginning of the first charge.

Case of Stationary Gap. When the spark gap is fixed, the spark always jumps, theoretically at least, when the potential difference reaches a certain definite value dependent on the bridged distance. Consequently, the discharge always takes place for the same voltage V.

Let $i_o'=i_o+\Delta i_o'$ be the initial current for the first charge, i_o being the current for tone phenomena corresponding to the potential difference V. Let $t_1=\tau+\Delta t_1$ (τ being the time of charging with tone phenomena). Then the time at which discharge occurs is a function of i_o' and is given by the equation

$$V=E\left(1-\frac{\varepsilon^{-at}\cos(\omega t-\phi)}{\cos\phi}\right)+\frac{L\omega i_o'}{\cos^2\phi}\sin\omega t\ \varepsilon^{-at}$$

or

$$V=E\left(1-\frac{\varepsilon^{-a(\tau+\Delta t_1)}\cos[\omega\tau+\Delta t_1-\phi]}{\cos\phi}\right)$$
$$+\frac{L\omega(i_o+\Delta i_o')}{\cos^2\phi}\sin\omega(\tau+\Delta t_1)\ \varepsilon^{-a(\tau+\Delta t_1)}$$

If Δt_1 and $\Delta i_o'$ are infinitesimal, this equation is equivalent to

$$\Delta t_1\left(\frac{\partial V}{\partial t}\right)_{t=\tau}+\Delta i_o'\left(\frac{\partial V}{\partial i_o'}\right)_{i_o'=i_o}=0, \qquad (41)$$

and determines Δt_1 as a function of $\Delta i_o'$.

The current, $i_1'=i_o+\Delta i_1'$ at the end of the first charge is given by the equation

$$i_1'=\frac{E}{L\omega}\varepsilon^{-at}\sin\omega t+\frac{i_o'}{\cos\phi}\cos(\omega t+\phi)\ \varepsilon^{-at}$$

Digitized by Google

If Δt_1 is infinitesimal, this equation becomes

$$\Delta i_1' = \Delta t_1 \left(\frac{\partial i_1'}{\partial t}\right)_{t=\tau} + \Delta i_o' \left(\frac{\partial i_1'}{\partial i_o'}\right)_{i_o'=i_o} \tag{42}$$

The elimination of Δt_1 between the two equations (1) and (2) gives $\Delta i_1'$ as a function of $\Delta i_o'$.

$$\Delta i_1' = \Delta i_o' \left[\left(\frac{\partial i_1'}{\partial i_o'}\right)_{i_o'=i_o} - \left(\frac{\partial V}{\partial i_o'}\right)_{i_o'=i_o} \frac{\left(\frac{\partial i_1'}{\partial t}\right)_{t=\tau}}{\left(\frac{\partial V}{\partial t}\right)_{t=\tau}}\right] \tag{43}$$

We have here

$$\left(\frac{\partial i_1'}{\partial i_o'}\right)_{t=\tau} = \frac{1}{\cos\phi} \cos(\omega\tau+\phi)\, \varepsilon^{-a\tau} \tag{44}$$

$$\left(\frac{\partial V}{\partial i_o'}\right)_{t=\tau} = \frac{L\omega}{\cos^2\phi} \sin\omega\tau\ \varepsilon^{-a\tau} \tag{45}$$

$$\begin{aligned}\frac{\partial i_1'}{\partial t} &= \frac{E}{L\omega}\varepsilon^{-at}(-a\sin\omega t+\omega\cos\omega t) \\ &\qquad + \frac{i_o'}{\cos\phi}\varepsilon^{-at}[-a\cos(\omega t+\phi) - \omega\sin(\omega t+\phi)] \\ &= \varepsilon^{-at}\frac{\sqrt{a^2+\omega^2}}{\omega}\left[\frac{E}{L}\cos(\omega t+\phi) - \frac{i_o'\,\omega}{\cos\phi}\sin(\omega t+2\phi)\right] \\ &= \frac{\varepsilon^{-at}}{\cos\phi}\left[\frac{E}{L}\cos(\omega t+\phi) - \frac{i_o'\,\omega}{\cos\phi}\sin(\omega t+2\phi)\right].\end{aligned}$$

For $t=\tau$, $i_o'=i_o$,

$$\left(\frac{\partial i_1'}{\partial t}\right)_{t=\tau} = \frac{\varepsilon^{-a\tau}}{\cos\phi}\left[\frac{E}{L}\cos(\omega t+\phi) - \frac{i_o\,\omega}{\cos\phi}\sin(\omega\tau+2\phi)\right]$$

and, substituting for i_o its value,

$$i_o = \frac{E}{L\omega}\frac{\varepsilon^{-a\tau}\sin\omega\tau}{1-\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}}$$

and simplifying, after remembering that

$$\cos^2(\omega\tau+\phi) + \sin\omega\tau\,(\sin[\omega\tau+2\phi]) = \cos^2\phi,$$

we have

$$\left(\frac{\partial i'}{\partial t}\right)_{t=\tau} = \frac{\varepsilon^{-a\tau}}{\cos\phi}\frac{E}{L}\frac{1}{1-\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}}\{\cos(\omega\tau+\phi) - \varepsilon^{-a\tau}\cos\phi\} \tag{46}$$

We know that

$$\left(\frac{\partial V}{\partial t}\right)_{t=\tau} = \frac{1}{C}i_o \tag{47}$$

Digitized by Google

from the general formula

$$C\frac{\partial V}{\partial t}=i$$

$$\left(\frac{\partial V}{\partial t}\right)_{t=\tau}=\frac{E}{CL\omega}\frac{\varepsilon^{-a\tau}\sin\omega\tau}{1-\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}}$$

If we now substitute in equation (43) the values found for the various factors, we obtain finally

$$\Delta i_1'=\Delta i_o'\left[\frac{1}{\cos\phi}\cos(\omega\tau+\phi)\,\varepsilon^{-a\tau}-\frac{CL\omega^2}{\cos^3\phi}\sin\omega\tau\;\varepsilon^{-a\tau}\frac{\cos(\omega\tau+\phi)-\varepsilon^{-a\tau}\cos\phi}{\varepsilon^{-a\tau}\sin\omega\tau}\right]$$

or, since

$$CL\omega^2=\cos^2\phi,$$

$$\Delta i_1'=\Delta i_o'\left[\frac{1}{\cos\phi}\cos(\omega\tau+\phi)\,\varepsilon^{-a\tau}-\frac{1}{\cos\phi}\left\{\cos(\omega\tau+\phi)-\varepsilon^{-a\tau}\cos\phi\right\}\right]\varepsilon^{-a\tau}$$

$$\Delta i_1'=\Delta i_o'\,\varepsilon^{-2a\tau} \tag{48}$$

The current at the beginning of the second charge is

$$i_1'=i_o+\Delta i_1'$$

and in the same way for i_2', the current at the beginning of the third charge, i_3' at the beginning of the fourth charge, . . . i_n' at the beginning of the $(n+1)$st charge:

$$i_2'=i_o+\Delta i_2'$$

$$\cdot\quad\cdot\quad\cdot\quad\cdot$$

$$i_n'=i_o+\Delta i_n'.$$

We obtain successively

$$\left.\begin{aligned}\Delta i_1'&=\Delta i_o'\,\varepsilon^{-2a\tau}\\ \Delta i_2'&=\Delta i_1'\,\varepsilon^{-2a\tau}\\ &\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\\ \Delta i_n'&=\Delta i_{n-1}'\,\varepsilon^{-2a\tau}\end{aligned}\right\} \tag{49}$$

Eliminating the quantities $\Delta i_1'$, $\Delta i_2'$, . . . there remains

$$\Delta i_n'=\Delta i_o'\,\varepsilon^{-2na\tau}$$

Consequently, $\varepsilon^{-a\tau}$ being smaller than unity, the musical phenomena are stable.

Digitized by Google

The effect of a momentary disturbance ceases to be appreciable after a certain number of sparks. The greater the damping and the longer the charging time, the more marked the stability.

Special Case of Maximum Efficiency. We have seen that the efficiency is a maximum when the time of charge, which is equal to the period of the tone phenomena, is also equal to a half period of the oscillations of the charge $\omega \tau = \pi$.

Now the initial current is $i_o = 0$. The potential difference at the condenser terminals is

$$v = E\left(1 - \varepsilon^{-at} \frac{\cos(\omega t - \phi)}{\cos \phi}\right)$$

In this special case, the sparking potential difference is equal to the absolute maximum of condenser potential difference during charging

$$V = E\left(1 + \varepsilon^{-\frac{\delta}{2}}\right)$$

The current value during the charging

$$i = \frac{E}{L\omega} \varepsilon^{-at} \sin \omega t$$

The average current in the charging circuit

$$i_{av} = \frac{\omega C E}{\pi}\left(1 + \varepsilon^{-\frac{\delta}{2}}\right)$$

The effective current in the charging circuit

$$i_{eff} = E\sqrt{\frac{C\omega}{4\pi L a}\left(1 - \varepsilon^{-\delta}\right)}$$

The potential difference at the inductance terminals during the charge

$$u = E\,\varepsilon^{-at} \frac{\cos(\omega t + \phi)}{\cos \phi}$$

This is a maximum and equal to

$$V_2 = E\,\varepsilon^{-at_2}$$

when

$$\omega t_2 = \pi - 2\phi.$$

Energy dissipated in the charging circuit

$$W_d = nCE^2\left(1 + \varepsilon^{-\frac{\delta}{2}}\right). \qquad \left(n = \frac{1}{\tau}\right).$$

Digitized by Google

Energy available at the condenser terminals

$$W_u = \frac{nCE^2}{2}\left(1+\varepsilon^{-\frac{\delta}{2}}\right)^2.$$

Efficiency

$$\gamma = \frac{1}{2}\frac{W_u}{W_d} = \frac{1+\varepsilon^{-\frac{\delta}{2}}}{2}$$

PART 2. CONDITIONS ARISING IN THE USE OF CONSTANT POTENTIAL GENERATORS FOR CHARGING CONDENSERS IN THE PRODUCTION OF RADIO FREQUENCIES.

In the case of radio telegraphy, we desire to obtain high efficiency for the case of oscillating charges and a low decrement in the charging circuit. Once the tone phenomena are taking place, the spark passes at regular intervals. After each spark the same initial conditions occur.

$$V=0 \quad \text{and} \quad i=i_o.$$

The best arrangement is that for which the time of charging is equal to a half-period of the free oscillation of the circuit (See Figure 11). In this Figure, the curves give the potential difference at the condenser terminals and the charging current.

The phènomena which occur are the following (shown in curves I and II of Figure 11):

Just before the extinction of the spark, the current and voltage at the condenser terminals are practically zero. Thereafter, the voltage increases continuously until time $\frac{T}{2}$, that of a half period of oscillating charge. At that time, the e. m. f. is approximately twice that of the generator.

The current starts at zero, increases to time $\frac{T}{4}$, then diminishes, and again comes to zero at time $\frac{T}{2}$.

If the discharger is so adjusted that the time between two sparks is equal to $\frac{T}{2}$ (which, as we have seen, corresponds to maximum efficiency), a spark will then pass, the condenser will be discharged, the spark will be extinguished, and the same series of phenomena will recur.

Digitized by Google

The oscillograms numbers 54, 12, 17, 18, 20, and 22 of Figure 12 give the current and voltages for the various cases.

Oscillogram 54—premature sparking. The condenser terminal potential difference (upper curve) increases as it leaves the origin. The current (lower curve) increases, reaches a maximum, and then decreases. Sparking occurs just before the maximum voltage is reached. The current still has an appreciable value at the moment of sparking.

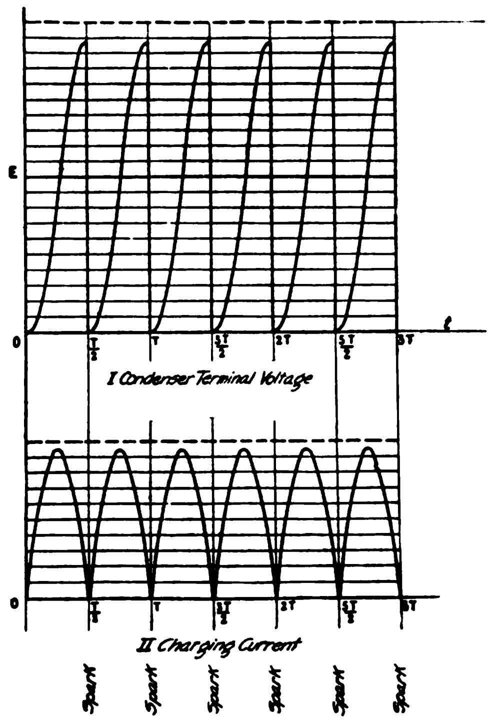


FIGURE 11—Successive Charges and Discharges of Condenser in Radio Transmitter. Charging by Constant E. M. F., Sparking at End of Each Half-Period of Charging Oscillation.

Oscillogram 12—Sparking at the maximum point, at the end of a half period of oscillation in the charging circuit. The voltage is a maximum at this time and the current zero.

Oscillograms 17, 18, 20—Slightly retarded sparking, on the

Digitized by Google

falling branch of the condenser potential difference curve. The current at sparking is negative, and increasingly larger.

Oscillogram 22—Greatly retarded sparking, after two and a half periods of the charging oscillation.

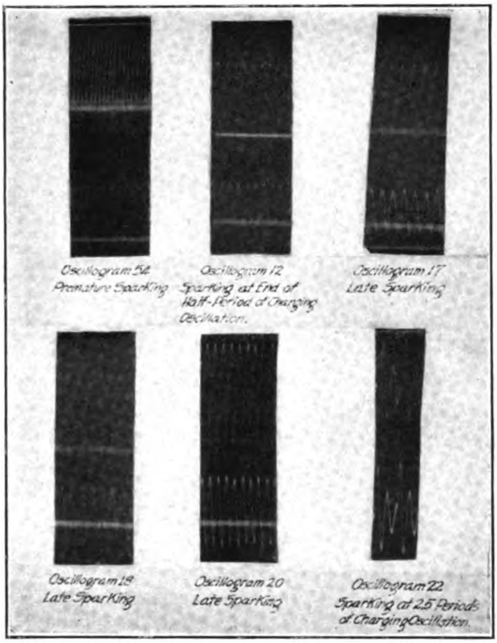


FIGURE 12—Oscillograms of Repeated Charging and Discharge of Condenser; Charging by a Direct Current Generator; Discharge in Oscillating Circuit with Rotary Gap. In all these oscillograms, the upper curve is the condenser terminal voltage; the lower curve the charging current

CHOICE OF THE CHARGING GENERATOR

We are here concerned with charging generators delivering voltages of the order of several tens of thousands of volts.

Use of Storage Battery Assemblies.

Until recent years, since high voltage generators had not been perfected to the point which has now been actually reached, the only solution which seemed available was the use of storage batteries. These were used by the Marconi Company at its Clifden station. The assembly of batteries at that station included 6,000 cells, and gave 12,000 volts.

Digitized by Google

The advantages of using storage batteries are the following: The e. m. f. is constant and is available at all times without the necessity of starting motors, the inductance is negligible, and consequently there is available a wide range of adjustment for obtaining different spark frequencies and different outputs with maximum efficiency.

The disadvantages seem to outweigh the advantages, and are the following: The inconvenience of a battery of several thousand cells is necessarily very marked, the difficulties of inspection and maintenance and repair are serious, insulation is troublesome to maintain in view of the high tensions and the presence of acid fumes which are continuously generated, and the cells, which even under the most favorable circumstances deliver only 70 per cent. of the energy which has been given them, have a poor efficiency. And, finally, the existence of the battery does not obviate the necessity of having high tension machines available, since they can be charged only by the use of a potential difference greater than their own on discharge.

All these disadvantages have prevented the spread of this system and made the plan of using high tension machines for charging condensers very attractive.

Direct Charging of Condensers by High Tension Direct Current Machines.

Until recent years, the highest voltages obtained by means of direct current machines was not greater than several thousand per machine. It was, consequently, useless to think of employing dynamos of such type for radio telegraphy. A system of energy transmission with direct current, developed by Mr. Thury, gave rise also to the problem of building high tension d. c. dynamos. The highest previously obtained voltage a few years before was not greater than 5,000. Next a voltage of 8,000 was reached, in the machines purchased by the Galletti Company from the Mechanical and Electrical Manufacturing Company (Compagnie de l'Industrie Electrique et Mécanique) at Geneva. A voltage of 10,000 was reached in a 10 kilowatt machine bought by the Department in 1913 for the radio telegraphic station at Ouessant and also in machines intended for use at the stations at Saintes-Mariès-de-la-Mer, Fort-de-l'Eau, Boulogne-sur Mer, and Bonifacio. Lately I have received several bids for the construction of machines delivering voltages of the order of 20,000. When we consider the difficulties which arise in the construction of such

Digitized by Google

machines, we cannot but admit that their production marks a real advance in electrical engineering and manufacture.

It can therefore be asserted that no serious difficulty stands in the way of securing directly by direct current machines the high voltages necessary for radio telegraphy.

Requirements of Machines and Conditions of Use.

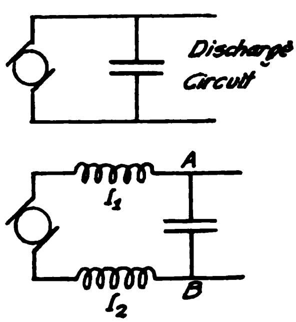
Experiments and tests in actual radio telegraphic service are aimed to determine the working conditions of the machines and the characteristics of the materials used.

1. At the moment of spark discharge, the potential is approximately double the charging e. m. f. The potential difference is never greater than twice the charging e. m. f. if a fixed gap is used, or if a rotary gap is employed of such type that the spark frequency is more than twice the frequency of the charging oscillation.

If the machine is connected directly to the terminals of the condenser, it must be so designed as to stand without danger a potential difference of twice the original e. m. f. However, to avoid this requirement, should it prove troublesome, it is merely necessary to insert in the charging circuit the inductances l_1, l_2 which must be insulated that they can stand sufficient potentials to protect the machine.

Oscillograms 75 and 76 show the potentials at the machine terminals and condenser terminals for a case where the inductance of the protecting chokes was about twice that of the machine.

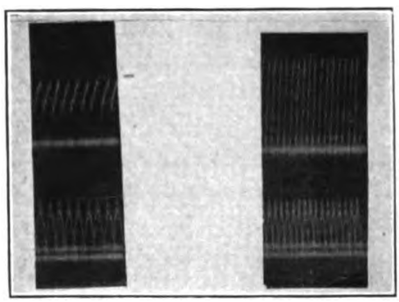
2. During the condenser discharge, the two ends of the charging system, A and B, are at a radio frequency potential difference. There are therefore produced near points A and B, or in the machine if no choke coils are provided, stationary



Auxiliary Figures A and B

Digitized by Google

waves. These may become very dangerous, since the insulation may be punctured by the large potentials developed at nearby points of the same coil by the radio frequency standing wave. It is therefore prudent to insert in the charging circuit between the points A and B some type of damping arrangement such as extremely well insulated choke coils with iron cores so designed that the Foucault (eddy) currents in the sheets shall be negligible for the charging frequency but large for the discharge frequency, and capable of damping rapidly the radio frequency wave. Often sufficient protection is obtained by increasing the insulation of the first few turns of the choke coils L, L.



AUXILIARY FIGURE C

Oscillogram 75
Upper Curve: Potential Difference, Machine Terminals. Lower Curve: Current in Charging Circuit

Oscillogram 76
Potential Difference, Condenser Terminals. Current in Charging Circuit

3. If it is desired that the sparks really occur at the end of a half period of charging, the number of sparks per second is

$$n = \frac{2}{T}$$

and since

$$T = 2\pi\sqrt{LC},$$

the inductance of the charging circuit is finally determined by the expression

$$n = \frac{1}{\pi\sqrt{LC}},$$

$$L = \frac{1}{\pi^2 n^2 C}.$$

Digitized by Google

C and n are generally determined by conditions outside of the charging circuit. The inductance is therefore fixed. It is necessary that the inductance of the machine shall be at most equal to this value. In case choke coils are used for lowering the potential difference at the machine terminals, it is desirable to design them so as to leave a certain margin for adjustment. The limitation of the inductance of the machine imposed by the above expression is sometimes troublesome. In that case, one is forced to diminish the inductance by means of compensating windings.

4. The armature of these machines is traversed, not by a continuous current, but by a pulsating current of frequency equal to that of the number of sparks per second. It is therefore necessary to design the iron thereof sufficiently finely subdivided so as to avoid serious energy losses from Foucault currents.

5. Lastly, if a rotary gap is used, the speed of rotation and the number of points on the disc must be controlled and held constant, in such a way that the time between the passage of two points passed the fixed electrode must be constant and equal to a half period of the charging circuit, if maximum efficiency is desired.

Choice of Type of Discharger

We have seen that for both stationary and rotary gaps tone phenomena are stable, are self-establishing, and are re-established after a momentary disturbance of the system. The re-establishment occurs the more rapidly the higher the damping of the charging circuit.

In the case of the rotary discharger, the charging time τ is constant theoretically; and we have seen that corresponding to even marked variations in the charging time τ with tone phenomena there are only slight changes in the sparking potential. It follows that accidental variations in the speed of the discharger cause only slight and momentary disturbances of the musical note. Indeed it is easy to avoid such variations in speed by driving the discharger from a special motor. In addition, the rapidly rotating discharger acts as a fly wheel and naturally opposes changes in speed.

In the case of the stationary discharger, theoretically the sparking potential is constant. But in reality it varies from one spark to the next, because of alterations in the sparking surfaces, alterations in the ionisation of the intervening air, etc. These changes follow complex laws which cannot be determined.

Digitized by Google

And we have seen, further, that corresponding to very slight variations in the potential difference giving tone phenomena there are large variations in the charging time and therefore in the pitch of the note. It follows that, while stable tone phenomena correspond to each sparking potential, it will be more difficult to obtain a pure musical note with constant pitch and intensity with a stationary gap than with a rotary gap.

Continual variations in the sparking potential have an additional disadvantage. Let us suppose that the sparking distance has been regulated in such a way that it corresponds to the tone phenomena occurring with one discharge per half period; that is, for maximum efficiency and maximum potential. If, thru any cause, the sparking potential is increased, the charging potential no longer reaches its maximum value, the condenser becomes completely charged by damped oscillations to potential E without a spark occurring, and the system is open. The unforeseen and continuous variations in the sparking potential of a fixed discharger thus prevent the obtaining of tone phenomena with maximum efficiency. It would be always necessary to be content with somewhat less. This is a second disadvantage of stationary gaps as compared with rotary gaps.

It follows from the above statements that, if no other considerations intervene, it is theoretically preferable to employ rotary dischargers in preference to stationary ones.

The preceding statements suppose also that the spark frequency is not far from that corresponding to maximum efficiency. If the actual phenomena are those of a much higher frequency ($\omega\tau$ very small, or the rising part of the curves of Figure 8) the contrary would be true. For this case, variations in sparking voltage caused by irregularities in the action of the fixed gap, even if these variations were marked, would not produce more than slight disturbances in the period of the tone, and the fixed discharger is capable under such circumstances of functioning very steadily. It is probably this case which was used by Mr. Blondel in his tests of radio telephony with direct current dynamos and fixed gaps.

It should finally be stated that with the fixed discharger, the period of the tone phenomena is always less than half the natural period of oscillation of the charging circuit ($\omega\tau < \pi$) and the potential difference is never greater than twice the e. m. f. of the generator, whereas with a rotary discharger, the period of the musical tone may have any value whatever.

For certain values of this period ($\omega\tau > \pi$) and a small damping,

Digitized by Google

the potentials may reach values much greater than twice the e. m. f. of the charging circuit. Consequently, a rotary discharger which is not properly regulated may be a dangerous arrangement in that the coils of the generator, the choke coils, and the charging condensers may be broken down by the excessive potentials, if the damping of the charging circuit is very small.

PART 3. THE PRODUCTION OF RADIO FREQUENCY ENERGY BY DIRECT CURRENT HIGH TENSION DYNAMOS AND ROTARY DISCHARGERS

The preceding discussion considers the operation of the Marconi system with storage batteries and rotary gaps; and it explains the good results obtained by Mr. Blondel with direct current machines, additional choke coils, and stationary gap. It also indicates how, being faced with the question of designing a type of station, we have chosen a definite combination of the previous elements, borrowing from each their best features and finally realising a step forward relative to each of them. In our stations, the condensers are charged by direct current, high voltage machines, with or without additional inductance or choke coils, and the discharge circuit includes a rotary gap.

Transmission cannot be accomplished by controlling the field circuit of the machine because of its large time constant. It is done by opening and closing the high voltage current where it leaves the generator. Because of the high tension, the switch or break is subdivided into several smaller portions, and the arc which tends to be formed is extinguished in the smaller stations by the air current from the rotary gap and in the larger stations by a separate blower.

Experiments have been made with system with powers reaching and exceeding 100 kilowatts, and charging voltages between 10,000 and 110,000 volts. These tests have demonstrated that between these limits, the use of the system presents no particular difficulty, and there is no reason why the same should not be the case for larger powers and still higher voltages.

The system has the following characteristics:

Digitized by Google

CHARACTERISTICS OF THE RADIO SYSTEM BASED ON HIGH VOLTAGE DIRECT CURRENT GENERATORS AND ROTARY DISCHARGERS

All necessary conditions being supposed fulfilled, we have obtained a system of the following characteristics:

1. The efficiency is equal to

$$\gamma = \frac{i + \varepsilon^{-\frac{\delta}{2}}}{2}$$

(δ being the logarithmic decrement of the charging oscillation). In the observed cases, using the oscillograph on normal installations, it (the charging circuit efficiency) is often greater than 0.9. δ is given by

$$\delta = \frac{R}{2L} T$$

where R is the effective resistance of the charging circuit (including losses in the iron, the dielectric of the condenser, and ohmic resistance), and L is the inductance of the charging circuit. T is the period of the charging oscillation. I have given previously the values of γ corresponding to different values of δ.

2. The note is always perfectly musical, since the interval between two sparks is equal to that between the successive passage of two points on the rotating disc past the fixed electrodes, and since conditions are precisely the same for successive sparks.

The tone phenomena are stable, self establishing, and the effect of momentary disturbances quickly disappears.

3. The period of oscillation of the charge is independent of the speed of the machine. Consequently, changes in machine speed produce no irregularity.

4. Even marked irregularity in the speed of the discharger do not have any influence on the efficiency.

5. The discharger is completely independent of the generator and can be driven by a special motor.

6. It is very easy to vary the power of the station by placing in series a greater or less number of machines. I have already used this method repeatedly. The practical characteristics of a system of charging condensers for radio telegraphy are valuable ones, and a comparison of the method here described with that normally employed at the present time, whereby charging is done by alternating current, brings out the value of the former.

Digitized by Google

Comparison of Characteristics of Installations Employing Direct Current for Charging Condenser with Those Using Alternating Current

Case of Charging by Constant E. M. F.	Case of Charging by Alternating E. M. F.
1. Material in which commutator bars are imbedded and rotating parts at high tensions.	1. Structure is sturdy, all high tension equipment in the charging circuit is fixed and can be placed in oil.
2. The speed of rotation of the machines does not interfere with regulation of the circuits.	2. The speed of rotation of the alternator must be maintained rigorously constant, a speed change causing a discrepancy between the frequency of the charging circuit and that of the alternator.
3. No effect of this type limits the efficiency, which in practice markedly exceeds 90 per cent.	3. The permissible excess voltage must be kept so small that variations of alternator speed in the wrong direction do not cause serious disturbances. This limits the maximum efficiency of the system to a theoretical value of 85 per cent., and considerably less in practice.
4. Even a marked change in the speed of the rotary gap causes only slight diminution of efficiency.	4. Even a slight displacement of the rotary gap from its normal position causes a marked diminution in efficiency.
5. The musical tone obtained is completely pure and clear.	5. It is theoretically possible to obtain a perfectly pure musical tone. It is very difficult in practice to obtain an acceptably clear tone.
6. The placing in series of several high tension machines is simple, and provides an easy means of regulating the available power.	6. Placing several alternators of the high (audio) frequency used for spark production in parallel is quite a delicate task.

Digitized by Google

Conclusions

This paper has for its object an explanation of the considerations which have led the Radio Service of the French Postal and Telegraph Department to a system wherein a direct current source charges condensers which are in turn discharged by means of rotary gaps.

The investigation shows

1. The theory of the use of direct current in charging radio telegraphic condenser.
2. The possibility of using such direct current machines.
3. The conditions under which such machines can be used, and the useful formulas in connection therewith.

This work has had a further practical aspect in that it has called the attention of constructors to high tension dynamos. The highest voltages obtained up to several years ago were a few thousand volts per machine. It is now possible to build these up to 25,000 volts per machine, and even further. This has been one of the most interesting steps forward for several years in the field of direct current dynamos.

Paris, February 28, 1916.

Note.—Since the compilation of the present paper, the question of using sparks from constant high potential generators in radio telegraphy has been discussed by A. Blondel ("Lumière Electrique," April 15, 1916, page 49). Furthermore, the system described above has been further developed and experimented with on a considerable scale. A 50-kilowatt station, operating at 1,800 meters wave length, is being installed at Saintes-Maries-de-la-Mer (France). In this station the Technical Committee of the Department of Posts and Telegraphs, in accordance with an early suggestion by A. Blondel, has required a condenser bank placed across the terminals of a series of machines which form the source of high voltage. The addition of this condenser produces certain advantages which will be considered at an early date.

Paris, April 21, 1917.

SUMMARY: The charging of condensers by high voltage direct current generators is discussed theoretically and practically. The stationary and rotary gaps are compared as dischargers, and the evolution of the system used by the French Department of Posts and Telegraphs is given.

Digitized by Google

VOLUME 5 AUGUST, 1917 NUMBER 4

PROCEEDINGS

of

The Institute of Radio Engineers

(INCORPORATED)

TABLE OF CONTENTS

TECHNICAL PAPERS AND DISCUSSIONS

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

PUBLISHED EVERY TWO MONTHS BY
THE INSTITUTE OF RADIO ENGINEERS, INC.
ONE HUNDRED AND ELEVEN BROADWAY
NEW YORK

THE TABLE OF CONTENTS FOLLOWS ON PAGE 235

Digitized by Google

GENERAL INFORMATION

The right to reprint limited portions or abstracts of the articles, discussions, or editorial notes in the Proceedings is granted on the express condition that specific reference shall be made to the source of such material. Diagrams and photographs in the Proceedings may not be reproduced without securing permission to do so from the Institute thru the Editor.

Those desiring to present original papers before the Institute of Radio Engineers are invited to submit their manuscript to the Editor.

Manuscripts and letters bearing on the Proceedings should be sent to Alfred N. Goldsmith, Editor of Publications, The College of the City of New York, New York.

Requests for additional copies of the Proceedings and communications dealing with Institute matters in general should be addressed to the Secretary, The Institute of Radio Engineers, 111 Broadway, New York.

The Proceedings of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings in New York, Washington, Boston or Seattle.

Payment of the annual dues by a member entitles him to one copy of each number of the Proceedings issued during the period of his membership. Members may purchase, when available, copies of the Proceedings issued prior to their election at 75 cents each.

Subscriptions to the Proceedings are received from non-members at the rate of $1.00 per copy or $6.00 per year. To foreign countries the rates are $1.10 per copy or $6.60 per year. A discount of 25 per cent. is allowed to libraries and booksellers. The English distributing agency is "The Electrician Printing and Publishing Company," Fleet Street, London, E. C.

Members presenting papers before the Institute are entitled to ten copies of the paper and of the discussion. Arrangements for the purchase of reprints of separate papers can be made thru the Editor.

It is understood that the statements and opinions given in the Proceedings are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

COPYRIGHT, 1917, BY

THE INSTITUTE OF RADIO ENGINEERS, INC.

ONE HUNDRED AND ELEVEN BROADWAY

NEW YORK, N. Y.

Digitized by Google

CONTENTS

Digitized by Google

OFFICERS AND BOARD OF DIRECTION, 1917

(Terms expire January 2, 1918; except as otherwise noted.)

PRESIDENT

MICHAEL I. PUPIN

VICE-PRESIDENT

JOHN L. HOGAN, JR.

TREASURER

LOUIS R. KRUMM

SECRETARY

DAVID SARNOFF

EDITOR OF PUBLICATIONS

ALFRED N. GOLDSMITH

MANAGERS

(Serving until January 7, 1920)

ERNST F. W. ALEXANDERSON
JOHN STONE STONE

(Serving until January 1, 1919)

EDWIN H. ARMSTRONG
GEORGE S. DAVIS

(Serving until January 2, 1918)

LOUIS W. AUSTIN
JOHN HAYS HAMMOND, JR.
LLOYD ESPENSCHIED
WARREN F. HUBLEY
ROY A. WEAGANT

ADVERTISING MANAGER

LOUIS G. PACENT

WASHINGTON SECTION

EXECUTIVE COMMITTEE

CHAIRMAN

LIEUT.-COLONEL GEORGE O. SQUIER
War Department,
Washington, D. C.

SECRETARY-TREASURER

GEORGE H. CLARK
Navy Department,
Washington, D. C.

CHARLES J. PANNILL
Radio, Va.

BOSTON SECTION

CHAIRMAN

A. E. KENNELLY,
Harvard University,
Cambridge, Mass.

SECRETARY-TREASURER

MELVILLE EASTHAM,
11 Windsor Street,
Cambridge, Mass.

SEATTLE SECTION

CHAIRMAN

ROBERT H. MARRIOTT,
715 Fourth Street,
Bremerton, Wash.

SECRETARY-TREASURER

PHILIP D. NAUGLE,
71 Columbia Street,
Seattle, Wash.

Digitized by Google

SAN FRANCISCO SECTION

CHAIRMAN	SECRETARY-TREASURER
W. W. HANSCOM, 848 Clayton Street, San Francisco, Cal.	V. FORD GREAVES, 526 Custom House, San Francisco, Cal.

H. G. AYLSWORTH
145 New Montgomery Street,
San Francisco, Cal.

PAST-PRESIDENTS

SOCIETY OF WIRELESS TELEGRAPH ENGINEERS

JOHN STONE STONE, 1907–8 LEE DE FOREST, 1909–10
FRITZ LOWENSTEIN, 1911–12

THE WIRELESS INSTITUTE

ROBERT H. MARRIOTT, 1909–10–11–12

THE INSTITUTE OF RADIO ENGINEERS

ROBERT H. MARRIOTT, 1912 GREENLEAF W. PICKARD, 1913
LOUIS W. AUSTIN, 1914 JOHN STONE STONE, 1915
ARTHUR E. KENNELLY, 1916

STANDING COMMITTEES

1917

COMMITTEE ON STANDARDIZATION

JOHN L. HOGAN, JR., *Chairman*	Brooklyn, N. Y.
E. F. W. ALEXANDERSON	Schenectady, N. Y.
EDWIN H. ARMSTRONG	New York, N. Y.
LOUIS W. AUSTIN	Washington, D. C.
FERDINAND BRAUN	Strassburg, Germany
A. A. CAMPBELL SWINTON	London, England
GEORGE H. CLARK	Washington, D. C.
WILLIAM DUDDELL	London, England
LEONARD FULLER	San Francisco, Cal.
ALFRED N. GOLDSMITH	New York, N. Y.
GUY HILL	Washington, D. C.
LESTER ISRAEL	Washington, D. C.
FREDERICK A. KOLSTER	Washington, D. C.
GEORGE H. LEWIS	Brooklyn, N. Y.
VALDEMAR POULSEN	Copenhagen, Denmark
GEORGE W. PIERCE	Cambridge, Mass.

Digitized by Google

JOHN STONE STONE	New York, N. Y.
CHARLES H. TAYLOR	New York, N. Y.
ROY A. WEAGANT	Roselle, N. J.
JONATHAN ZENNECK	Munich, Germany

COMMITTEE ON PUBLICITY

DAVID SARNOFF, *Chairman*	New York, N. Y.
JOHN L. HOGAN, JR.	Brooklyn, N. Y.
ROBERT H. MARRIOTT	Seattle, Wash.
LOUIS G. PACENT	New York, N. Y.
CHARLES J. PANNILL	Radio, Va.
ROBERT B. WOOLVERTON	San Francisco, Cal.

COMMITTEE ON PAPERS

ALFRED N. GOLDSMITH, *Chairman*	New York, N. Y.
GEORGE H. CLARK	Washington, D. C.
MELVILLE EASTHAM	Cambridge, Mass.
JOHN L. HOGAN, JR.	Brooklyn, N. Y.
ALEXANDER MEISSNER	Berlin, Germany
SIR HENRY NORMAN	London, England
WICHI TORIKATA	Tokyo, Japan

SPECIAL COMMITTEES

COMMITTEE ON INCREASE OF MEMBERSHIP

WARREN F. HUBLEY, *Chairman*	Newark, N. J.
J. W. B. FOLEY	Port Arthur, Tex.
LLOYD ESPENSCHIED	New York, N. Y.
JOHN L. HOGAN, JR.	Brooklyn, N. Y.
DAVID SARNOFF	New York, N. Y.

Digitized by Google

THE MEASUREMENT OF RADIOTELEGRAPHIC SIGNALS WITH THE OSCILLATING AUDION*

By

LOUIS W. AUSTIN

(UNITED STATES NAVAL RADIOTELEGRAPHIC LABORATORY, WASHINGTON, D. C.)

For the measurement of received signals at a great distance, no methods have been found possible except those involving the use of the telephone. Even tho galvanometer methods have been developed which are sufficiently sensitive, the disturbances due to atmospheric discharges are so troublesome that it is found impracticable to use them under many circumstances. For purposes of measurement the audibility of telephone current is defined as the ratio $\frac{i}{i_o}$ where i is the given current, and i_o is the least current of the given frequency audible in the telephone to the given observer.[1] This ratio is determined experimentally by shunting the telephones so that the sound in the telephones just remains audible. Then if t is the effective resistance of the telephones for the given frequency and telephone pulse form, and s is the value of the shunt, the audibility

$$A = \frac{i}{i_o} = \frac{t+s}{s}$$

The best method for making this measurement seems to be, when such an arrangement is possible, to have test letters sent which are heard by one observer in unshunted telephones and which are heard by the observer taking the audibility in shunted telephones. The shunt is gradually reduced until the observer fails to get the letters correctly. In this way, if the room be perfectly quiet and there are no atmospheric disturbances, errors of observation may be reduced to about ten per cent. Under ordinary station conditions the errors are seldom less than twenty

*Received by the Editor, October 31, 1916.

[1]The uniformity of audibility readings made by different trained observers has been very much underestimated. Of the half dozen or more men who have been engaged in this kind of work in the laboratory only one, who was known to be a little deaf, obtained results in general differing from the others by more than twenty per cent.

Digitized by Google

per cent and sometimes reach fifty per cent or even more under very bad atmospheric conditions.[2]

This method of making telephone measurements in radio telegraphy, in the case of electrolytic and crystal contact detectors, has been studied by several workers.[3]

The extensive use of three electrode vacuum tubes for the reception of continuous oscillations has rendered a similar study of the shunt telephone method for these detectors desirable.

Calibration of the Audibility Box

The arrangement of apparatus is shown in Figure 1. Here *A* is a wave meter circuit excited either by means of an audion

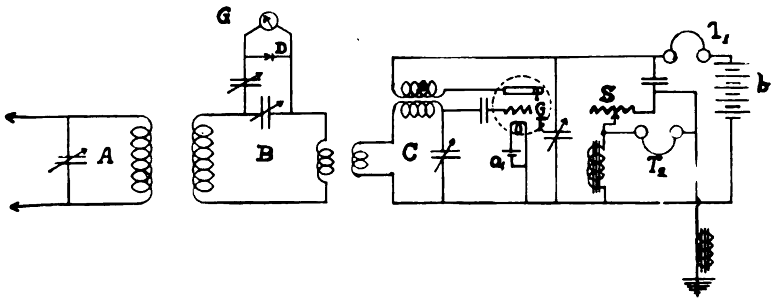


Figure 1

or buzzer, *B* is an intermediate circuit or artificial antenna, *C* is the receiving circuit corresponding to the usual receiving secondary. The current in circuit *B* was varied by changing the coupling *A B* while the range of audibility in the receiver *C* for each experiment was fixed by the coupling *B C*. The radio frequency current in *B* was measured relatively by means of a silicon detector and galvanometer. It was, of course, impos-

[2]In general, in radio stations, the audibility readings tend to be too low on account of atmospheric disturbances, disturbing noises in the station. and lack of proper adjustment of the apparatus.

[3]F. Braun, "Jahrb. d. drahtl. Telegraphie," **8**, p. 203, 1914.

L. W. Austin, "Bulletin of the Bureau of Standards," **7**, p. 319, 1911, Reprint 159.

Klages and Demmler, ("Jahrb. d. drahtl. Tel.", **8**, p. 212, 1914), using a contact detector attempted to find a linear relation between sending current and telephone shunt value. In some reviews and references their lack of success has been quoted as an argument against the use of the shunted telephone method for quantitative measurements. Their own observations when recalculated using a probable value for their telephone resistance, show a fair linear relation between sending current squared and audibility as defined above.

Digitized by Google

sible to get readings on the galvanometer, covering the whole range of telephone audibilities from 1 to 5,000, especially since the silicon responds in proportion to the square of the high frequency current, while the audibilities of the oscillating audion are proportional to the first power.[4] The galvanometer could not be shunted during a series, as it was found to affect the sensitiveness of the detector.

The audibility shunt resistance used with the audion telephones was of a type already described.[5] Its range extended from 1 to 5,000 audibility in 34 steps controlled by a single movable contact arm. The box was calibrated to read directly in audibility when used with telephones having an effective resistance of 5,000 ohms at the given tone frequency. The telephones used had a direct current resistance of 2,040 ohms, and a current sensitiveness at 1,000 sparks per second, of 5×10^{-10} amperes.

In making the measurements, while keeping the coupling BC fixed, the coupling AB was varied and the corresponding audibilities and galvanometer readings noted. The coupling BC was then changed and the observations repeated for a new audibility range, care being taken that the coupling BC never became close enough to permit the local oscillations in the audion circuit to affect the detector in circuit B. In this way the ratio of the current in circuit B to the audibility readings was determined for various measurement ranges of the audibility box.

Table I shows the proportionality between audibility and received current over five ranges where the current is proportional to the square root of the detector galvanometer deflections in circuit B. The variations shown are well within the limits of experimental error.

TABLE I

Ranges of Audibility	$\frac{\text{Ratio of Current}}{\text{Ratio of Audibility}}$	Sets of Observations
1 – 2	0.95	6
1 – 10	0.93	6
10 – 100	0.94	5
100 – 2000	1.05	7
250 – 5000	1.03	16

[4] "Journ. Washington Acad.," **6**, p. 81, 1916.
[5] "Journ. of the Washington Acad.," **3**, p. 133, 1913.

Digitized by Google

Table II shows the detailed observations for a set taken between 3 and 80 audibility. From these results it may be concluded that, under the given experimental conditions, the shunted telephone method gives results which are correct within the limits of experimental error.

TABLE II

Audibility Ratio	Current Ratio	$\frac{\text{Current Ratio}}{\text{Audibility Ratio}}$
$\frac{12}{3}$	$\frac{5.24}{1.14}$	1.15
$\frac{20}{3}$	$\frac{7.78}{1.14}$	1.02
$\frac{50}{3}$	$\frac{19.24}{1.14}$	1.01
$\frac{80}{3}$	$\frac{28.8}{1.14}$	0.95
$\frac{20}{12}$	$\frac{7.78}{5.24}$	0.89
$\frac{50}{12}$	$\frac{19.24}{5.24}$	0.89
$\frac{80}{12}$	$\frac{28.8}{5.24}$	0.85
$\frac{50}{20}$	$\frac{19.24}{7.78}$	0.99
$\frac{80}{20}$	$\frac{28.8}{7.78}$	0.93
$\frac{80}{50}$	$\frac{28.8}{19.24}$	0.93

The above direct method of calibration is better than the usual one involving a determination of the impedance of the telephones. This is difficult to determine for the very small currents occurring in actual reception, and in addition it obviates the uncertainties due to changes in the total current pulse intensity when the shunt is closed.

Digitized by Google

Absolute Sensitiveness of the Oscillating Audion

The relative audibility of the oscillating audion and the old type audion for buzzer signals has been determined many times, the average ratio being about 600. Similar comparisons have been made between the old audion and the free wire electrolytic, with the result that the mean sensitiveness of the old audion is found to be 1.7 times that of the electrolytic. The extreme deviations with different bulbs are 1.5 and 1.8. At the time of the Brant Rock tests[6] a rather careful determination was made of the number of watts in the receiving system required to give an audible signal for normal ears in the telephones then used with the electrolytic. This was determined to be 25×10^{-10} watts. With the improvement in telephones this has been reduced to about 12.25×10^{-10} watts. From all these data, it was estimated that the least power capable of producing a signal on the oscillating audion is 1.2×10^{-15} watts using 2,000 ohm telephones having a current sensitiveness of 5×10^{-10} amperes at 1,000 cycles. From this value a table[7] was calculated on the assumption that the oscillating audion produces a current variation in the telephone proportional to the square root of the received watts.[8]

In order to obtain a more certain knowledge of audion sensitiveness, a direct determination of the power in the receiving system corresponding to unit audibility in the oscillating audion has recently been made. The method used is practically that used in the Brant Rock experiments. The arrangement of apparatus, Figure 2, was with slight modifications that shown in Figure 1. The sending wave meter *A* was excited by an oscillating audion capable of giving out several watts, thus making it possible to use loose coupling between the circuits *A* and *B*. The detector in circuit *B* was removed, and a sensitive vacuum thermoelement of 28 ohms resistance was placed directly in the circuit. This thermoelement with the galvanometer used gave a deflection of 1 millimeter (0.04 inch) for 40.4×10^{-6} amperes in the *B* circuit. A double pole, double throw switch was introduced in the *C* circuit so that the receiving circuit proper could be connected to the audion or to a silicon detector and galvanometer. Using the silicon detector in the *C* circuit with the coupling *B C* adjusted so as to give the largest deflection on the silicon galvanometer, a comparison was made between the ther-

[6] "Bulletin Bureau of Standards," 7, p. 315, Reprint 159, 1911.
[7] "Proc. I. R. E.," 4, p. 255, 1916.
[8] "Journ. Washington Acad.," 6, p. 81, 1916.

Digitized by Google

moelement deflections in circuit B and the detector deflections in C. By exterpolation it then became possible to use the detector galvanometer in C to measure the radio frequency currents in B, even when small enough to bring the response of the oscillating audion within the range of the audibility box when the audion was connected to the secondary receiving circuit C.

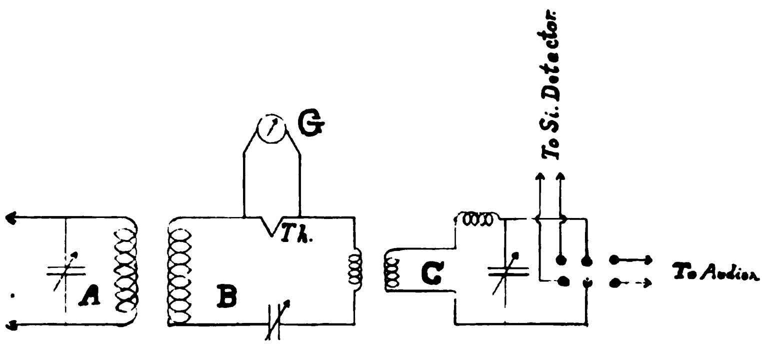


FIGURE 2

The sensibility of the audion depends very much on the adjustments of its circuits. It is therefore necessary to choose some definite method of making these adjustments. The following method, while not giving the greatest sensibility, seems to give the most easily reproducible readings: The antenna and closed circuit are first tuned for best signal at very loose coupling, adjusting the bridging condenser, grid condenser, and re-inforcing coupling, if one is used. Then the main coupling is gradually closed to the best point and the secondary retuned slightly for the note desired, leaving the antenna unchanged.[9]

The audibility observations were made by the test letter method already mentioned. Three wave lengths were used in the measurements: three thousand meters, six thousand meters and ten thousand meters. The inductance in the secondary C for three thousand meters was approximately twelve mh. At six thousand meters, observations were made with an inductance

[9] In order to prevent false readings, if the signals are stronger than 100 audibility it is necessary to ground one side of the observing telephones thru a suitable choke (pair of 2,000 ohm telephones) to prevent the effects due to the capacity of the observer's body. To prevent the breaking down of the oscillations a high resistance (a hundred thousand ohms or more) may be placed across the grid condenser, or the grid may be grounded thru a condenser of a few ten-thousandths microfarad.

Digitized by Google

of twelve mh. and also with thirty-six mh. At ten thousand meters thirty-six mh. were used.

In Table III the complete data for a set of observations at three thousand meters are given. Here D is the detector gal-

TABLE III

$\lambda = 3{,}000$ m. $R = 65$ ohms. $L_c = 12$ m h.
1 mm. deflection of Si detector galvanometer $= 6.2(10)^{-6}$ amp. in circuit B.

D mm.	$\sqrt{D}$	I 10^{-6} amps.	W 10^{-10} watts	A	W_o 10^{-15} watts
2.3	1.52	9.4	57.2	2,500	0.92
4.0	2.00	12.4	100.1	3,000	1.11
2.0	1.41	8.7	50.1	2,000	1.25
2.2	1.48	9.2	55.2	2,300	1.02
4.0	2.00	12.4	100.1	3,000	1.11
					1.09 Average

vanometer deflection, I is the current in circuit B, W is the watts in circuit B, A is the corresponding audibility on the audion, and W_o is $\frac{W}{A^2}$ or watts for unit audibility. The total resistance R of the table is the resistance of the B circuit plus the resistance due to coupling the C circuit with the silicon detector attached. This sum amounts to 1.7 of the resistance of the B circuit alone.

In Table IV the mean values of the power required for unit audibility for the given wave lengths are given.

TABLE IV

λ meters	L_c m h.	W_o 10^{-15} watts
3,000	12	1.09
6,000	12	1.72
6,000	36	1.55
10,000	36	1.51
		1.45 Average

Since the watts are proportional to audibility squared, and audibility is by far the least accurate of the observed quantities, the accuracy of the value of watts for unit audibility is not very

Digitized by Google

high. If we assume the error in the mean value of the audibilities to be 20 per cent., which is certainly great enough under the actual experimental conditions, the error in watts for unit audibility would be 40 per cent. We can then consider the probable minimum value of this quantity for our telephones and observers roughly as 1×10^{-15} watts, and the maximum value 2×10^{-15} watts. The value found by the comparison of the oscillating and non-oscillating audions, 1.2×10^{-15} watts, lies within these limits. The E.M.F. produced on the antenna by the incoming waves, and the received antenna current, which are from the theoretical standpoint the most important quantities derived from the observations in long distance work have the same error as the audibility readings.

SUMMARY: After considering procedure and accuracy in the measurement of audibility by the shunted telephone method, the author gives an arrangement for calibrating a usual audibility box when it is employed in conjunction with an oscillating audion. The method is found to be accurate to better than 20 per cent., exactly as with other detectors.

The absolute sensitiveness of the oscillating audion is found to be $1.2(10)^{-15}$ watts for a just audible signal. This is more than $(10)^6$ times the watt sensitiveness of the electrolytic detector and $6(10)^5$ times that of the normal audion on buzzer signals.

The details of the measurements and the necessary precautions are described in detail.

Digitized by Google

DISCUSSION

Edwin H. Armstrong: Dr. Austin's paper is naturally of great interest to me as I have often wondered just how sensitive the oscillating audion really was and how small an amount of energy was needed to give an audible response. To my knowledge, there has been no reliable determination of the absolute sensitiveness of this device, and for this reason it is very gratifying to have available the results of Dr. Austin's work along these lines. The method of calibration employed by Dr. Austin is somewhat involved and for this reason I would like to withhold comment on it until able to study it in detail.

There is one matter, however, on which I would like to comment and that is the standard of audibility which is now in general use. Primarily when we speak of the audibility of a signal in a telephone we have the concept of the energy necessary to produce that signal. We would naturally suppose that when a telephone is supplied with four times the energy necessary to give unit audibility that the audibility of that signal would be four. Certainly the amount of energy which has gone into the production of sound waves is four times that necessary for unit audibility. But by the present standard, since the telephone current is only twice the value of the current necessary for unit audibility, the audibility is only two. This leads to an absurdity in the case of the oscillating audion receiver. One of the great virtues of this receiver, or in fact of nearly all heterodyne receiving systems, is that the energy delivered to the telephones is directly proportional to the received energy. But according to the present definition of audibility it becomes necessary to say that the audibility is proportional to the square root of the received watts! I again like to call attention to the treatment of this audibility question by Mr. Lester Israel ("PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS," Volume 3, 1915, page 183), which covers the ground in complete detail.

It is very difficult to appreciate the great amount of work involved in preparing such a paper as the one presented by Dr. Austin unless one has been engaged along similar lines. The number of experiments and tests which must be made before work can be begun on the main object is surprising and will never appear from the relatively few pages of "PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS," in which the data are condensed. We are greatly indebted to Dr. Austin for the results of what must have been a long and tedious series of experiments.

Digitized by Google

Carl R. Englund: The audibility method of obtaining an estimate of the strength of radio signals is one of the same type as the "transmission" one used in measurements on wire telephone lines. Both are convenient and simple, since the actual procedure differs so little from commercial working of the apparatus, and are very practical in the sense of requiring minimum apparatus and operator skill. The second method, however, is normally a comparison one, the unknown line (loop) being compared with a known and variable line and the "transmission equivalent" is thus found, independent in great measure of the actual signal strength or detecting apparatus. There is in my mind no question that a similar transmission "coefficient" is the logical thing to measure in radio work, though impractical at present. The quotient $\frac{\text{watts radiated}}{I_s \times I_R}$ is as truly a circuit constant as the resistance of a piece of wire.

However, while a measurement of the above "coefficient" is not feasible, a comparison of the strength of the unknown signal with that of a known signal is possible and it seems to me very much preferable to the normal audibility method. It is true that Dr. Austin's data give proof that working results are possible, but the shunted telephone in these days of sensitive detectors and amplifiers is electrically too far away from the antenna, where the quantity to be measured is located, to allow anyone to feel safe without recalibrating the apparatus so often that a comparison method might as well have been adopted at once. To use such a method requires only a local generator with current indicator and a network for supplying to the antenna a known fraction of this current. Taking for granted the proposition that most of the measurements required in the future will be on sustained wave signals, the construction of a simple suitable generator is admittedly solved by the vacuum tube oscillator and the subdividing network offers no serious diffculty. I should, therefore, like to insist both on the desirability and practicability of the comparison method. It can be made accurate enough to meet most requirements without sacrificing manipulative simplicity or low cost.

May 26, 1917.

J. Mouradian: One or two points suggest themselves as worth while mentioning in connection with Dr. Austin's very interesting paper. In reference to the subject of percentage of error for observations made as to audibility, it has been the

Digitized by Google

writer's experience that for any given individual the maximum error of a single observation, under the ideal conditions of freedom from room noises and other disturbances, will likely be as high as fifty per cent.; the average error of a series of observation varying, under the same conditions, from five to fifteen per cent. As between different individuals, the writer's experience has not been as encouraging as Dr. Austin's, the variation, as between individuals under the same ideal conditions of freedom from interfering noises, running as high as three hundred per cent. This figure was obtained for a group of five normal observers. Outside noises will seriously react upon the audibility for any given individual and to a different extent for different individuals. Under medium conditions of noise, such as obtains in the center of metropolitan areas, the audibility will vary, as an average for a number of observers, between three hundred and four hundred per cent. It is conceivable that under the conditions of observation which probably obtained at the United States Naval Radiotelegraphic laboratory in Washington, the audibility was not quite as seriously affected by outside or room noises.

In reference to the second part of the paper, the interesting set of measurements indicated on table III as to absolute sensitiveness of the oscillating audion appear to be indicative of the amplification power of the oscillating audion rather than of its sensitiveness. The values shown for the ratio of watts input to the audibilities squared (which is proportional to the watts output) will vary with the type of receiver used, and is consequently not a particularly good characteristic figure, in so far as the oscillating audion proper may be concerned. It may also be a question whether the ratios indicated on the last column of table III will not vary materially, if instead of working within the audibility range of 2,000 to 3,000, a different range of audibilities had been used.

May 30, 1917.

Edwin H. Armstrong (communicated): Upon considering in greater detail Dr. Austin's method of determination of the absolute sensitiveness of the oscillating audion receiver, it appears to me that a matter has been overlooked which will tend to give a greater sensitiveness than really exists, and for this reason the following analysis is submitted for consideration.

Briefly Dr. Austin's method is carried out in two steps. The first step consists in producing in an artificial antenna a

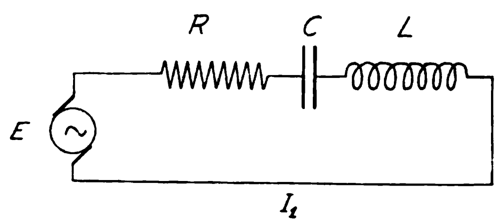
Digitized by Google

current from a local source and measuring this current by means of a calibrated rectifier and galvanometer connected in a secondary circuit which is coupled to the antenna to the critical degree (i. e., that coupling which gives maximum current in the secondary). The second step consists in replacing the rectifier and galvanometer by an audion with the usual regenerative circuits, adjusting the same in accordance with a pre-determined method and measuring the audibility of the signal thus obtained. On the basis that the received power in the antenna is equal to the square of the antenna current multiplied by 1.7 times the effective resistance of the antenna circuit and the fact that the audibility of the telephone signal is proportional to the antenna current, the power in the antenna for unit audibility is calculated.

This calculation is based on the assumption that the power received in the antenna from the signaling source is the same whether the circuit coupled to the antenna contains a crystal rectifier or a regenerative tube. Because of a curious and valuable property of the regenerative circuit, the above assumption does not hold good, and the reason therefore will appear from the following simple treatment.

Assume first a simple antenna circuit such as shown in the figure of Case I and represent the electromotive force set up by an incoming signal by an alternator giving a potential E_1.

Case I



For resonance the current I_1, is given by

$$I_1 = \frac{E_1}{R}$$

and the power supplied to the circuit by the source E_1 is given by

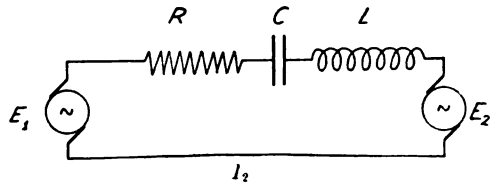
$$P_1 = E_1 I_1 = I_1^2 R$$

Now consider that there is introduced in the circuit of case I, a second electromotive force E_2 of exactly the same frequency

Digitized by Google

as E_1 and for the sake of simplicity, exactly in phase with E_1. This is the case of the regenerative circuit, whether in the stable or unstable state, and it may be represented by the figure of Case II. E_1 represents the signaling electromotive force and E_2 represents the final value in the steady state of the regenerative electromotive force.*

Case II



In general practice the electromotive force E_2 is introduced into the antenna thru the medium of the coupling coils and might therefore be shown across coil L instead of being shown conventially in series therewith.

The new current I_2 is now given by

$$I_2 = \frac{E_1 + E_2}{R}$$

and the total power P_2 in the circuit by

$$P_2 = (E_1 + E_2)\, I_2$$

The total amplification of the power in the antenna by the process of regeneration is given by the ratio of P_2 to P_1

$$A = \frac{P_2}{P_1} = \frac{(E_1 + E_2)\, I_2}{E_1\, I_1} = \left(\frac{E_1 + E_2}{E_1}\right)^2$$

The power P_2 in the antenna is made up of two components; the power received from the signaling source which will be called P_2', and the power supplied by the regenerative action of the tube, which will be called P_2''.

$$P_2' = E_1\, I_2$$

$$P_2'' = E_2\, I_2$$

* In receiving by the heterodyne method there would, of course, be a third electromotive force acting on the circuit. This applies whether the receiving is accomplished by a regenerative audion in the stable state with an external heterodyne or whether the regenerative circuit is adjusted to be in the unstable state and used as a self-heterodyne. This third electromotive force, however, is of a different frequency from the other two and need not be considered in matters affecting only the principle of regeneration.

Digitized by Google

Now it will be observed that *the power P_2' received from the signaling source when the local electromotive force E_2 is acting is not the same as the power P_1 received from the signaling source when the electromotive force E_2 is absent.* The power P_2' is the greater, and the greater by an amount depending on the relative magnitudes of E_2 and E_1.

$$\text{Hence}\qquad \frac{P_2'}{P_1}=\frac{E_1 I_2}{E_1 I_1}=\frac{E_1+E_2}{E_1}$$

The *increase* in power drawn from the signaling source is proportional to

$$\frac{P_2'-P_1}{P_1}=\frac{E_1 I_2-E_1 I_1}{E_1 I_1}=\frac{E_2}{E_1}$$

The effect of the local or regenerative electromotive force E_2 is therefore to increase the power which is supplied to the system by the signaling source. A simple analogy is afforded by comparing the work done by a single cell battery when it is connected alone in a circuit, and again when it is connected in the same circuit with a second and similar cell in series. The total power delivered by the two is four times that of the single cell; each cell by reason of the presence of the other in the circuit does twice the work it would if placed in the circuit alone.*

It is obvious from the foregoing that when the crystal rectifier and galvanometer were replaced by a regenerative audion that the power in the antenna received from the signaling source was immediately increased by an amount approximately the ratio $\frac{E_2}{E_1}$. Hence the absolute sensitiveness as determined by Dr. Austin is too great by this ratio. As the ratio depends entirely on the adjustment, it is, of course, problematical what the error is, but from such measurements as I have made of the regenerative amplification occuring when the audion is in the oscillating state it would seem to be of the order of 1,000 per cent., altho it may readily be greater.

* It is important at this point to consider the limitations of the foregoing analysis. It has been assumed thruout that the electromotive force E_1 stayed constant regardless of the amount of power drawn from the signaling source by the action of the electromotive force E_2. In the case of an artificial antenna, such as used by Dr. Austin in his calibration, the assumption is strictly correct, as the power in the antenna is certainly very small compared to the power available in the wave meter circuit. But in the case of reception on a real antenna the proposition is not so simple, as the power available in the incoming waves and the power actually received by the antenna approach each other more closely than in the case of the artificial antenna just considered. If it should so happen that the antenna constituted an overload for the energy available in the waves, then the value of E_1 will decrease and the foregoing considerations of the amount of amplification obtainable will not be quantitatively correct.

Digitized by Google

Many measurements have been made of the power of received signals with an oscillating audion receiver having this faulty calibration and close agreement has been obtained between these measured values and the values obtained by calculation with the Austin formula. [Notably the reception of signals at the U. S. Bureau of Standards from Nauen and Eilvese, "Journal of the Franklin Institute," November, 1916.] It is very probable that this close agreement has been obtained because the same type of error occurs in applying any of the standard formulas to predict the current in an antenna to which a regenerative receiver is attached. The error in the calculated current is numerically equal to the error made in the calibration of the receiving set (on the basis that E_1 remains constant) and of the proper sign to give compensation. For example take the Austin formula

$$I_R = \frac{377\, h_1 h_2 I_S}{\lambda d R} \varepsilon^{-\frac{0.0015 d}{\sqrt{\lambda}}}$$

This formula was derived from experimental results obtained with crystal and electrolytic detectors. As long as the electromotive force produced in the antenna by the signaling waves is the only electromotive force of that frequency in the circuit the formula is applicable, but with the use of regeneration the current in the antenna becomes many times that given by the formula, the increase being given by the ratio E_1 which it is clear is the same as the error in the calibration of the receiver. The formula, E_1 for use with regenerative circuits, may be written

$$I_R = \frac{377\, h_1 h_2 I_S}{\lambda d R} \varepsilon^{-\frac{0.0015 d}{\sqrt{\lambda}}} + \frac{E_2}{E_1} \frac{377\, h_1 h_2 I_S}{\lambda d R} \varepsilon^{-\frac{0.0015 d}{\sqrt{\lambda}}}$$

$$I_R = \left(1 + \frac{E_2}{E_1}\right) \frac{377\, h_1 h_2 I_S}{\lambda d R} \varepsilon^{-\frac{0.0015 d}{\sqrt{\lambda}}}$$

On account of the presence of the electromotive force E_2, it becomes necessary to use terms in their proper sense and the term "received current" should particularly be avoided, since its use will give rise to all sorts of difficulties. The electromotive force due to the incoming waves and that part of the power in the antenna which is actually drawn from the energy of these waves are the only quantities which can properly be termed "received." In terms of current and the effective resistance of the antenna the received power is given by

$$P_2' = I_2^2 R \frac{1}{\left(1 + \frac{E_2}{E_1}\right)}$$

and the power supplied by regeneration by

$$P_2'' = I_2^2 R \frac{1}{\left(1+\frac{E_1}{E_2}\right)}$$

As a general proposition, in view of the difficulty of obtaining the value of the ratio of E_2, or of maintaining it constant by means of so delicate an adjustment as is necessary with the regenerative circuit it would appear preferable to make measurements of received power with a simple vacuum valve detector and an external heterodyne properly arranged to prevent regeneration. While the sensitiveness of this arrangement is not so great, it is a very constant quantity and it can be correctly calibrated by the method described in Dr. Austin's paper. In conclusion, I would like to state that such modifications as have been made of the Austin formula are quantitatively correct only as long as the electromotive force induced in the antenna by the signaling waves stays constant. Until data is available as to what extent regeneration on an efficient antenna can be carried without overloading the signaling waves quantitative relations are problematical.

Digitized by Google

ON THE POULSEN ARC AND ITS THEORY*

By

P. O. PEDERSEN

(PROFESSOR IN THE ROYAL TECHNICAL COLLEGE, COPENHAGEN, DENMARK)

CONTENTS

*Received by the Editor, November 8, 1916. Some of the results set forth in this paper have been communicated to "Det skandinaviske Naturforskermøde" in Christiania, Norway, July, 1916.

Digitized by Google

INTRODUCTION

Many investigations have been made in order to elucidate the working of the Duddell-Poulsen arc. Besides the papers of Duddell†[1], [2], and Poulsen[3], [4], I shall mention only a few of the most important contributions. A long series of papers contributed by H. Th. Simon[5], [6], [7], and his school (H. Barkhausen[8], G. Lange[9], M. Reich[10], K. W. Wagner[11], and many others) have thrown much light upon the subject. A. Blondel[12] has made a very interesting oscillographic study of the Duddell arc. Of investigations of a more general character, but bearing on this subject, I may mention G. Granqvist's[13] papers on the influence of the heat conductivity of the electrodes on the behaviour of the arc, and the arc theories put forward by J. Stark[14], [15] J. J. Thomson,[16] and by C. D. Child.[16¹]

Thru the above mentioned papers and several others, some knowledge has been gained relative to the main features of the Poulsen arc—but this knowledge is far from being complete. The effect of the magnetic field, for instance, has not been explained so far in any satisfactory way, the current explanations being incomplete and very often misleading. A really satisfactory theory of the operation of the Poulsen arc does not exist at present, a satisfactory theory being one which will enable the calculation of the results, the necessary data being given.

It is, in most cases, impossible to state, even qualitatively,

† The figures refer to the bibliography given at the end of the paper The notation used in this paper is also tabulated at the end of the paper.

Digitized by Google

by means of the present "theory," what will be the result of a change in one or more of the constants of the arc circuit or of the arc itself. That others are also feeling the insufficiency of the present theory appears from a paper by A. O. Liljeström[17] (of which see especially part 1).

While in spite of very extensive labor in this field, nothing truly satisfactory has been reached, such a state of affairs is mainly due to the great difficulties met with in analyzing oscillations of such high frequencies—that is, in obtaining reliable oscillograms of the potential difference and current. The investigations have, therefore, generally been limited to the Duddell arc at low frequencies, usually around 300 to 1000 cycles per second. An exception to this statement is found in some records made by means of the Braun tube. H. Hausrath[18] has described a method in which the rays of a Braun tube are made to describe some kind of a stationary Lissajous curve under the influence of the potential difference or current in the arc circuit, and in a secondary circuit in resonance for the high or radio frequency current and loosely coupled to the arc circuit. The shape of the Lissajous curve gives, then, the necessary information for drawing up the voltage and the current curves. Experience shows, however, that a loosely coupled secondary circuit may greatly affect an arc generator—causing, for example, considerable variations in the frequency. The explanation of these phenomena is indicated by P. O. Pedersen[21]. Furthermore, this method necessitates a comparatively long time of exposure—20 seconds or more—so that the Lissajous figure gives only a sort of average curve for several million cycles. Finally, the currents used are of such small value—the maximum being 3 amperes—that these investigations are of little value so far as the normal Poulsen arc is concerned. (See below.) Besides those mentioned, other circumstances have also contributed to the lack of success of the efforts to unravel the theory of the Poulsen arc. Nearly all of the above mentioned investigations have been carried out with comparatively small laboratory sets, using very small energy—the feeding current usually being only a few amperes. It is a fact, however, as will appear from the following, that in many respects simpler relations are found in the larger arc generators, carrying heavy currents, than in small ones. The operation of small and large arcs is rather different; and for this reason, many of the previous laboratory investigations are of little value for testing the theory of the Poulsen arc.

Digitized by Google

During some years I have had an opportunity to carry out several investigations in connection with the Poulsen arc, and in the present paper I shall report some of the results obtained. After a short description of the apparatus and arrangements used, the paper will be divided into two parts: **A** and **B**. The first—**A**—deals briefly with the theory of the Poulsen arc from an engineering point of view. In **B** I shall attempt to develop further the theory and comprehension of the arc; and particularly to explain the results obtained under **A** and the influence of the magnetic field. *On several points, I shall arrive at results differing considerably from those so far obtained.*

Most of the investigations were carried out in the Laboratory for Telegraphy and Telephony of The Royal Technical College in Copenhagen. I have had excellent assistance from engineers J. P. Christensen, H. Trap-Friis, and E. Jacobsen in carrying out the tests and experiments, from engineer Hugo Fortmeier while working out the paper and the drawings, from the mechanic at the laboratory, Folmer Nielsen in all the photographic work. I especially desire to thank Dr. Poulsen for the great interest he has taken in this investigation.

Apparatus and Arrangements

Figure 1 shows a schematic diagram of the arc generator, while Figure 2 is a more explicit diagram of the arrangement used. Figure 3 is a photograph of the arc generator employed,

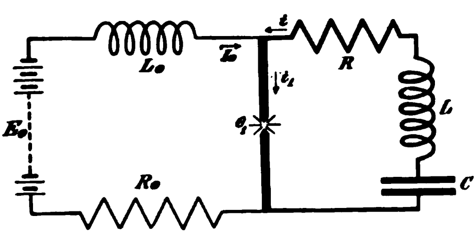


FIGURE 1—Duddell and Poulsen Arc

sketches of the electrodes being shown in Figure 4. The anode is of copper, hollow, and water-cooled, while the active part of the cathode is formed of a carbon ring d, screwed on to a copper rod a, which is slipped into a brass tube b. P indicates one of the pole pieces of the electromagnet creating the magnetic field in which the arc is placed. The direction of the field is arranged so as to force the arc upward, and its intensity, H, is

Digitized by Google

measured with a Grassot fluxmeter. The distance between the electrodes can be accurately regulated by rotating the hard rubber cylinder, visible in Figure 3, thus displacing the cathode. The starting of the arc is effected by pushing on the thinner hard rubber pin protruding thru this cylinder. The cathode is rotated slowly by means of the small electric motor also visible in Figure 3. The actual distance between the electrodes is much less than shown in Figure 4—being approximately one millimeter (0.04 inch).

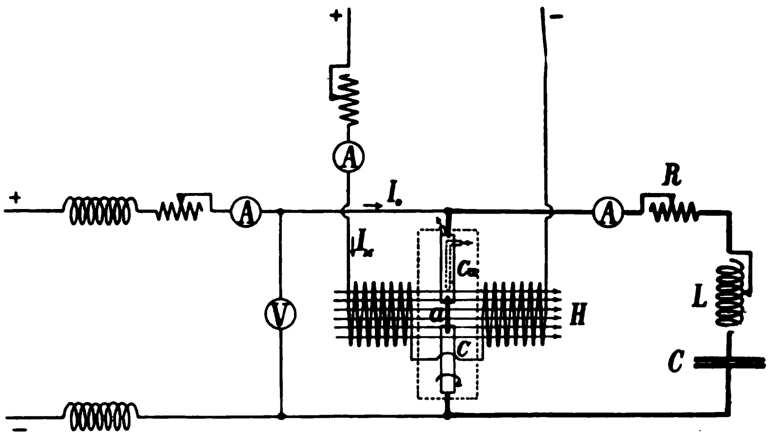


FIGURE 2—Complete Diagram for Arc Used in the Experiments

The capacity C in the arc circuit was composed of one or more oil condensers (containing castor oil), four of these being available and each one having a capacity of about 7,300 cm. (0.00811 microfarad). The inductance L was 70 turns of a copper helix of 5 mm. (0.2 inch) bare solid wire wound on a hard-rubber frame. The total inductance was 1.3×10^6 cm. (0.0013 henry). The resistance R in the arc circuit was made of carbon rods, its design being shown in Figure 5. The effective resistance of the arc circuit, with the carbon resistance short-circuited, was between 0.5 and 1.0 ohm; but as the work here considered is not intended to deal with efficiency determinations, R does only signify the value of the inserted carbon resistance when speaking about the experiments, altho it means the total effective resistance of the arc circuit in all theoretical calculations. The choke coils were made of stranded copper cable with a total inductance of 0.1 henry.

Digitized by Google

For power supply, there was used, according to circumstances, either 220 or 440 volts from the city supply, and for the magnetic field a local 110 volt storage battery was used. In most cases, the arc was burned in coal gas taken right from

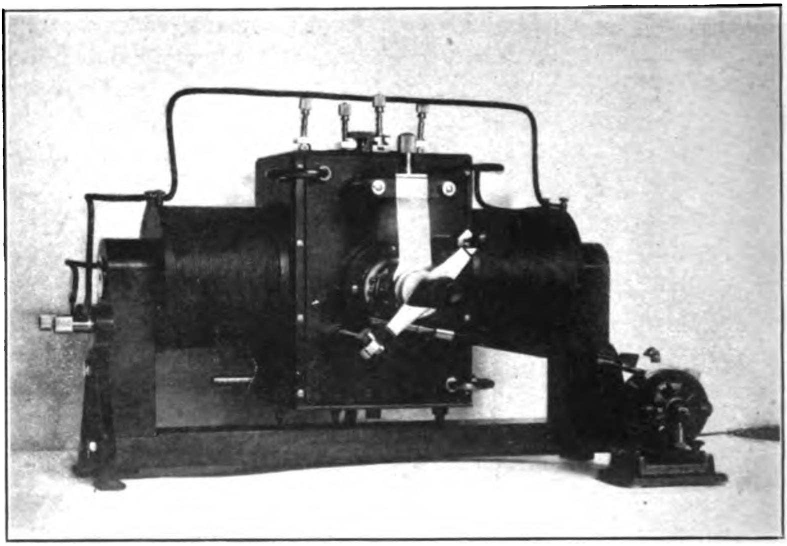


FIGURE 3—Photograph of the Arc Generator

the city pipes; but in a few cases hydrogen was used, compressed in steel containers. Where the latter is the case, it is always pointed out in the description of the experiments.

For the greater portion of the experiments, one pole piece, P_2, and the corresponding coil, as shown in Figure 6, were removed and the hole in the arc chamber covered with a mica window, g_2, thru which a side view of the arc then could be photographed

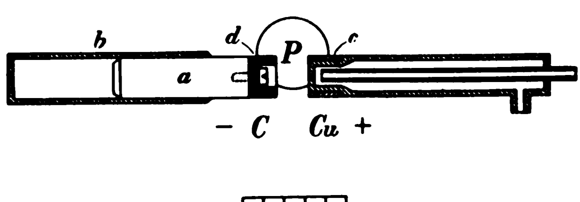


FIGURE 4—Cross Section of the Electrodes

Digitized by Google

by means of the lens, B_2, the shutter, L_2, and the photographic plate, FP_2. The lid of the chamber was provided with a projecting cylindrical portion with a mica window, g_1, on its top. Thru this window, by means of the lens, B_1, the metal mirror, Sp_1, and the shutter, L_1, either a stationary crater picture could be photographed on the plate, FP_1, or—when using the rapidly rotating metal mirror, Sp_2—the varying states of the crater and the arc could be photographed on the plate, FP_3, with the time as abscissa. The latter kind of pictures will in the following be called crater

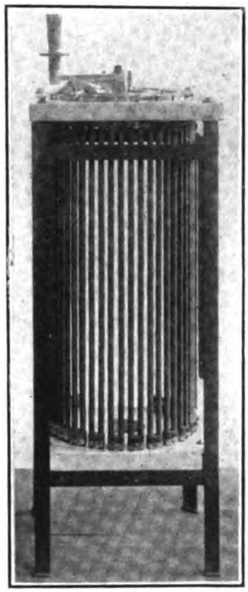


FIGURE 5—Carbon Rod Resistance

oscillograms. The rotary plane mirror was from a Gehrcke cathode glow oscillograph (see, for example, J. Zenneck, "Lehrbuch der drahtlosen Telegraphie," 2nd. edition, 1913, Figure 8, or Zenneck-Seelig, "Wireless Telegraphy," 1st. edition, 1915, Figure 8), and also the bibliography, numbers 25 and 6. This oscillograph was also employed when taking the oscillograms of the potential difference on the arc, as described later. The mirror could be rotated as rapidly as 200 revolutions per second.

Digitized by Google

A

1. *a*. Ratio of Radio Frequency Current to Supply Current

The only way to deal with the Poulsen arc, until a satisfactory theory has been evolved, obviously is to establish some empirical relations between the effective values of the different currents and voltages. The first question of interest is, then, how the ratio g between the effective value of the radio frequency current I and the feeding current I_0* is affected by the constants of the circuit, the design of the arc, the primary voltage, and other circumstances. K. Vollmer[22] is probably the only

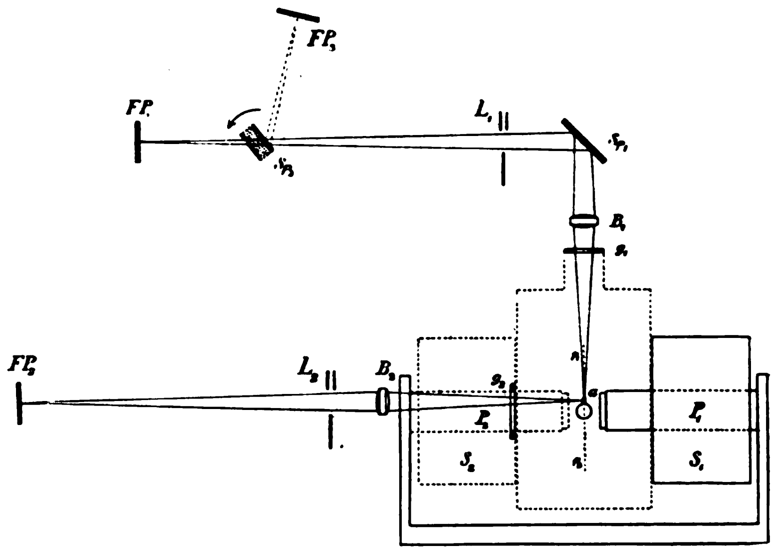


Figure 6—Sketch of the Photographic Arrangement

investigator who has published anything with regard to this question. Working on wave-lengths from 300 to 1,915 m., and with a supply current of from 1 to 7 amperes, he found $g=0.77$. The characteristic of the arc circuit $\varrho=\sqrt{\frac{L}{C}}$ was between 30 and 1,300 ohms. W. Duddell[1] found $g=0.90$ when $I_0=5$ amperes, J. A. Fleming[23] $g=0.63$ when $I_0=8$ amperes, L. W. Austin[24], found $g=1$ when $I_0=4$ amperes with $\lambda=3{,}600$ m. and $\varrho=4.5$

* For the notation used in this paper, see "List of Symbols," page 315 at the end of the paper.

Digitized by Google

ohms, while Fassbender and Hupka[20] found $g=0.83$ when $I_o=1.1$ amperes, $\lambda=3{,}180$ m. and $\varrho=567$ ohms.

For the normal Poulsen arc—by which I mean an arc that is working with at least 10-15 amperes d. c. with $\lambda=1{,}000$ m. or more, and a value of ϱ not less than 50 ohms—*this ratio has the value*

$$g=\sqrt{\frac{1}{2}}=0.707. \tag{1}$$

Under such conditions as are generally to be found in the larger arc stations, or when using similar laboratory arrangements, the formula (1) holds good with such accuracy that even with the best engineering design of ammeters for radio frequency current, no disagreement can be found. *Near the above mentioned limits, and after passing them, g will assume higher values.*

b. Calculation of Supply Current or Voltage

Calling the effective resistance of the arc circuit R, the primary voltage V_o, and the efficiency factor of the arc γ, we have

$$\gamma I_o V_o = I^2 R = \frac{1}{2} I_o^2 R$$

or

$$2\gamma V_o = I_o R \tag{2}$$

The value of γ is not constant but will, in practice, be known approximately, and the formulas (1) and (2) then provide a very simple method for dertermining the values of V_o and I_o necessary for producing a given radio frequency current I.

2. *a.* The Most Advantageous Adjustment of the Arc.

Another important consequence of formula (1) is this: *As the ratio g is constant, the arc must give maximum of efficiency when V_o is a minimum.* With the arc burning on a power supply of voltage V_o, and with a constant resistance in the d. c. circuit, the arc must consequently give a maximum efficiency when I_o (or I) is a maximum. *In order to obtain the maximum of I under given circumstances, a certain distance between the electrodes and a certain value of the magnetic field is required, and these values are greatly dependent on the constants of the circuits.* Arc generators are therefore built so as to allow adjustment of the distance between the electrodes, and with a variable magnetic field. The arc is not active until pulled out to a certain critical length—for shorter arc-lengths, it works as an ordinary d. c. arc. Having reached the active length, however, the arc can be shortened a little without losing its activity (see V. Poulsen[4*], page 966).

Digitized by Google

The arc then gives maximum current I with as short a distance as possible between the electrodes; i. e., the critical distance or a little less. By increasing the distance, I will decrease and finally the arc is extinguished. Similar conditions exist with regard to the magnetic field. *The arc works most efficiently with a field just strong enough to keep it steady;* but this question will be taken up later in this paper.

b. THE CONVERSION OF THE ARC FROM THE INACTIVE TO THE ACTIVE STATE

It appears from the preceding that the arc generator either is active and supplies a radio frequency current equal to or larger than $\sqrt{\frac{1}{2}}I_o$, or does not operate at all (that is, is inactive) The r. f. current does not start as a small fraction of the value of I_o and then gradually increase as the conditions improve. It is therefore easily understood that even comparatively small changes in the condition of the arc can be the deciding factors as to its ability to operate as a radio frequency generator, since such small changes may just carry it past the critical point. This explains why it can be of such vital importance that the arc should burn in hydrogen instead of air, even tho the difference between these two gases in most other respect is only of a quantitative nature.

B

3. ARC THEORY BASED ON BARKHAUSEN'S SIMPLE CHARACTERISTIC

The present view with regard to the working of the arc generator has been crystallized in the theory of Barkhausen[8a], based on his idealized simple characteristic shown in Figure 7, and only this theory has such a concrete form that the problem can be dealt with mathematically. Most modern literature dealing with the arc theory is therefore also based on Barkhausen's simple characteristic (see, for example, pages 260–293 in the excellent book by Zenneck, mentioned above). *For the sake of brevity in the following discussion, we shall call this view the B-theory.*

A question of immediate interest is, therefore, whether the value of the ratio g found above is in accord with the consequences of the B-theory or not. Before investigating this question we will, however, draw some mathematical conse-

Digitized by Google

quences of the B-theory, using the symbols indicated on Figures 7 to 9, the meanings of which are further explained under "List of Symbols" at the end of this paper. Figures 8 and 9

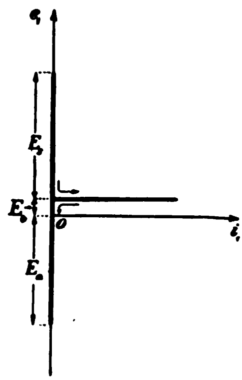


FIGURE 7—Barkhausen's
Simple Characteristics

show the current thru the arc and in the r. f. circuit and the voltage across the arc and the condenser, the calculations being based on the characteristic shown in Figure 7. In Figure 8, $R=0$ while in Figure 9, $R>0$.

In the following, it is assumed that the choke coils in the supply cables are so great that the supply current I_o is constant, and this is correct practically.

For the sake of clearness, we will first take the ideal case with no resistance in the arc circuit.

a. $R=0$

While the arc is burning, the current in the radio frequency circuit is (see Figure 8)

$$i=I_m \sin(\omega_o t-\phi),$$

where

$$\omega_o=\frac{1}{\sqrt{LC}}.$$

While the arc is extinguished is $i=-I_o$. The time is reckoned from the moment i_1 begins, i. e., the instant the arc is struck. For $t=0$, we have, then

$$-I_o=i=-I_m \sin\phi,$$

Digitized by Google

consequently
$$\sin\phi = \frac{I_o}{I_m}. \tag{3}$$

The potential difference across the condenser e is determined by
$$e = e_1 + L\frac{di}{dt}, \tag{4}$$

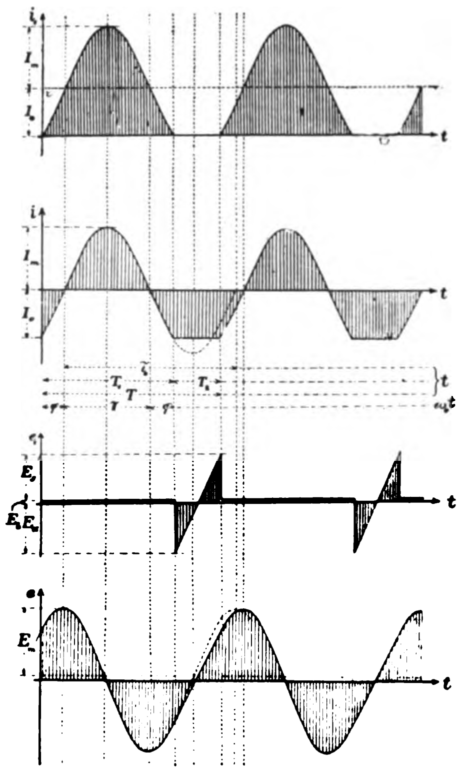


FIGURE 8—Current and Voltage Curves Corresponding to Barkhausen's Simple Characteristic $R=0$

where e_1 is the voltage of the arc. Equation (4) assumes two different forms according to whether the arc is burning or extinguished. These forms are respectively
$$e = E_c + \omega_o L\, I_m \cos(\omega_o t - \phi), \tag{5a}$$
when the arc is burning, and
$$e = e_1, \tag{5b}$$
when the arc is extinguished.

Digitized by Google

For $t=0$, we have further

$$e=e_1=E_s+E_c,$$

therefore, in consequence of (5a),

$$E_s=\omega_0 L\, I_m \cos\phi=\rho\, I_m \cos\phi=\rho\sqrt{I_m^2-I_o^2}, \tag{6}$$

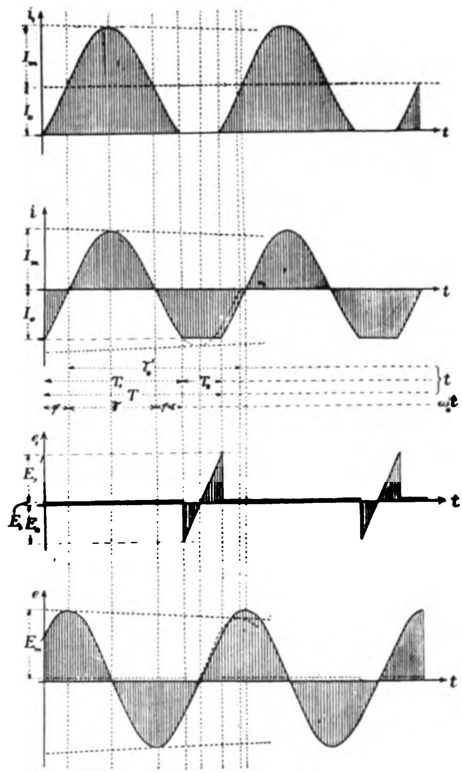


FIGURE 9—Current and Voltage Curves Corresponding to Barkhausen's Simple Characteristic $R>0$

or

$$\frac{I_m^2}{I_o^2}=1+\left(\frac{E_s}{\rho\, I_o}\right)^2=1+k^2, \tag{7}$$

where

$$k=\frac{E_s}{\rho\, I_o} \text{ and } tan\,\phi=\frac{1}{k}. \tag{8}$$

The period T can be divided into two parts: the burning period T_1 and the extinguished period T_2. Calling the natural

Digitized by Google

period of the radio frequency circuit $\tau_o = \frac{2\pi}{\omega_o}$, we have (see Figure 8)

$$T_1 = \frac{1}{2}\tau_o + \frac{2\phi}{2\pi}\tau_o,$$

and $$I_o T_2 = C\,(E_s + E_c - E_a) = 2\,C\,E_s,$$

or $$T_2 = 2\,C \cdot \frac{E_s}{I_o} = 2\,\omega_o L C \frac{I_m}{I_o} = \frac{\tau_o}{\pi} \cdot \cot\phi. \tag{9}$$

The ratio f_o between the actual period $T = T_1 + T_2$ and the natural period τ_o is consequently

$$f_o = \frac{T}{\tau_o} = \frac{1}{2} + \frac{1}{\pi}(\phi + \cot\phi) = \frac{1}{2} + \frac{1}{\pi}\left(\tan^{-1}\frac{1}{k} + k\right). \tag{10}$$

We have

$$\tan^{-1}\frac{1}{k} = \frac{\pi}{2} - k + \frac{1}{3}k^3 - \frac{1}{5}k^5 + \cdots$$

which, inserted in (10), gives

$$f_o = 1 + \frac{k^3}{3\pi} - \frac{k^5}{5\pi} + \cdots \tag{11}$$

Figure 10 shows the value of f_o as a function of k. It appears that only for values of k larger than 0.2 do we find f_o deviating noticeably from the value 1.

The ratio g_o between the effective value I of the current in the r. f. circuit and the d. c. I_o is determined by:

$$g_o^2 = \frac{\frac{1}{\omega_o} \cdot \int_o^{\pi} I_m^2 \cdot \sin^2(\omega_o t) \cdot d(\omega_o t) + \frac{2}{\omega_o} \cdot \int_o^{\phi} I_m^2 \sin^2(\omega_o t) \cdot d(\omega_o t) + T_2 I_o^2}{\tau_o f_o I_o^2}$$

$$= \frac{I_m^2\left(\frac{\pi}{2} + \phi - \frac{1}{2}\sin 2\phi\right) + 2 I_o^2 \cot\phi}{2\pi f_o I_o^2} = \frac{(1+k^2)\left(\frac{\pi}{2} + \phi\right) + k}{2\pi f_o}$$

$$= \frac{1}{2}\left(1 + k^2 - \frac{k^3}{\frac{\pi}{2} + \tan^{-1}\frac{1}{k} + k}\right). \tag{12}$$

Figure 11 shows how g_o is dependent on k.

For small values of k, (12) becomes

$$g_o = \sqrt{\frac{1}{2}(1+k^2)} = \left(1 + \frac{1}{2}k^2\right)\sqrt{\frac{1}{2}}, \tag{13}$$

Digitized by Google

or, if we can cancel $\frac{1}{2}k^2$ as small compared to 1,

$$g_o = \sqrt{\frac{1}{2}} = 0.707.$$

For small values of k, the value of g_o is very nearly equal to this limit.

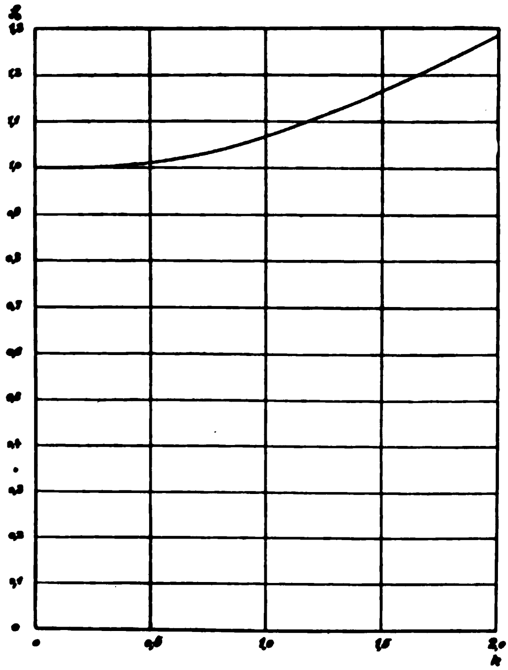


FIGURE 10—Ratio of the Period of the R. F. Current to the Natural Period of the R. F. Circuit. (With the parameter k as abscissa)

By inserting the value of k taken from (8) in (12), g_o is obtained as a function of $\frac{I_o}{I_m}$, and this function is shown in Figure 12.

We find without difficulty that $g_o = \sqrt{\frac{1}{2}}$ for $\frac{I_o}{I_m} = 1$, and that the tangent to the curve in this point makes an angle ψ with the axis where $\tan \psi = -\sqrt{\frac{1}{2}}$.

Digitized by Google

For values of $\frac{I_o}{I_m}$ not differing considerably from 1, we have with a good degree of approximation (see Figure 12)

$$g_o = \left(2 - \frac{I_o}{I_m}\right)\sqrt{\frac{1}{2}}. \tag{14}$$

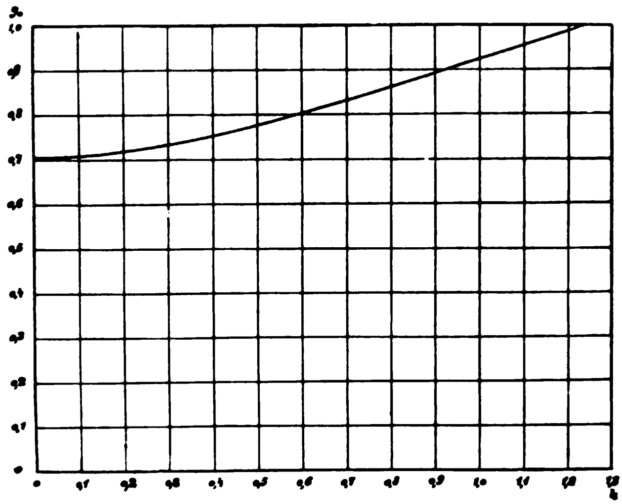


FIGURE 11—Ratio of the Effective Value of R. F. Current to the Supply Current. (With the parameter k as abscissa)

b. $R > 0$.

While the arc is burning, the current i in the r. f. circuit can be written

$$i = I_m \cdot \varepsilon^{-\kappa t} \cdot \sin\left(\omega_o' t - \phi\right) \tag{15}$$

When the arc is extinguished, $i = -I_o$.

For $t=0$, both cases give the same value of i, namely, $i = -I_o$. Consequently we have

$$\sin\phi = \frac{I_o}{I_m} = \frac{1}{\sqrt{1+k^2}}. \tag{16}$$

While the arc is burning, the potential difference across the condenser is determined by:

$$e = E_b + R\,i + E_m \cdot \varepsilon^{-\kappa t} \cos\left(\omega_o' t - \phi - \chi\right). \tag{17}$$

As i is the discharge current of the condenser, we must have

$$-i = C \cdot \frac{d\,e}{d\,t},$$

Digitized by Google

consequently

$$I_m \sin(\omega_o' t-\phi) = CE_m\left[\kappa \cos(\omega_o' t-\phi-\chi)+\omega_o' \sin(\omega_o' t-\phi-\chi)\right]. \\ -R\frac{di}{dt} \qquad (18)$$

From this we obtain the following approximate formula:

$$E_m = \varrho I_m \text{ and } \tan\chi = \frac{\kappa}{\omega_o} = \frac{R}{2\varrho}. \qquad (19)$$

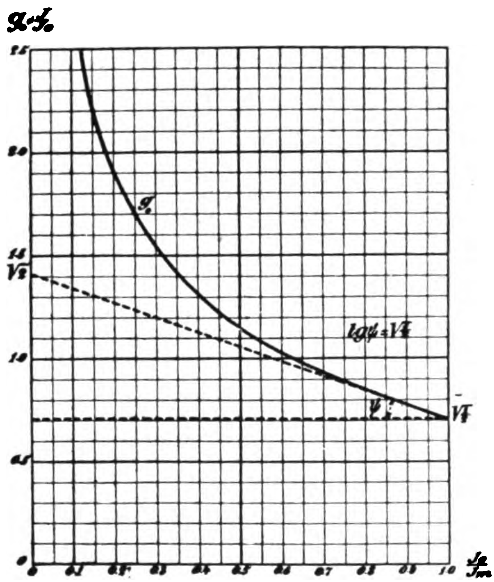


FIGURE 12—Ratio of the Effective Value of R. F. Current to the Supply Current. (With the Ratio $\frac{I_o}{I_m}$ as abscissa)

As the arc is supposed to strike or ignite just as $t=0$, the following equation must be satisfied:

$$E_s = I_o R + E_m \cdot \cos(\phi+\chi). \qquad (20)$$

Herein

$$\cos(\phi+\chi) = \frac{k}{\sqrt{1+k^2}} - \frac{1}{\sqrt{1+k^2}} \cdot \frac{\kappa}{\omega_o}, \qquad (21)$$

and, inserting this in (20), we obtain

$$E_s = k\,\omega_o L\, I_o + \frac{1}{2} R\, I_o.$$

Digitized by Google

or
$$k=\frac{o}{\omega_o L}\left(\frac{E_s}{\varrho I_o}-\frac{R}{2\varrho}\right)=\frac{E_s}{\varrho I_o}-\frac{R}{2\varrho} \tag{22}$$

In most cases, (22) may be written
$$k=\frac{E_s}{\varrho I_o}. \tag{23}$$

Determination of the Period.

The time during which the arc is burning is, as above stated, T_1, that during which it is extinguished, T_2, and the complete period T is therefore $T=T_1+T_2$.

For the determination of T_2, we have
$$I_o T_2=C\,(E_s+E_b-E_a)=LC\left[\left(\frac{d\,i}{d\,t}\right)_{t=0}-\left(\frac{d\,i}{d\,t}\right)_{t=T_1}\right]. \tag{24}$$

Here we have
$$L\frac{d\,i}{d\,t}=I_m L\,[\omega_o'\,cos\,(\omega_o t-\phi)-\kappa\,sin\,(\omega_o' t-\phi)]\,\varepsilon^{-\kappa t}, \tag{25}$$

and therefore
$$E_s=L\left(\frac{d\,i}{d\,t}\right)_{t=0}=I_m L\,(\omega_o'\,cos\,\phi+\kappa\,sin\,\phi),$$

and
$$E_a-E_c=L\left(\frac{d\,i}{d\,t}\right)_{t=T_1}=I_m L\,[\omega_o'\,cos\,(\omega_o' T_1-\phi)-\kappa\,sin\,(\omega'_o T_1-\phi)]\,\varepsilon^{-\kappa T_1}$$

The moment of extinction T_1 is determined by
$$-I_o=I_m\,\varepsilon^{-\kappa T_1}\,sin\,(\omega_o' T_1-\phi),$$
or
$$sin\,\phi+\varepsilon^{-\kappa T_1}\,sin\,(\omega_o' T_1-\phi)=0. \tag{26}$$

From the expression for E_s and E_a-E_b we obtain when using (26)
$$E_s-(E_a-E_b)=\omega_o' L\,I_m\,[cos\,\phi-\varepsilon^{-\kappa T_1}\,cos\,(\omega_o' T_1-\phi)]. \tag{27}$$

We have very approximately $\omega_o'=\omega_o$, and we will always use this approximation in the following discussion. The last equation then reduces to
$$T_2=\frac{1}{\omega_o\,sin\,\phi}\cdot[cos\phi-\varepsilon^{-\kappa T_1}cos\,(\omega_o T_1-\phi)].$$

The ratio f between the period T of the radio frequency current and the natural period τ_o of the r. f. circuit is consequently determined by:
$$f=\frac{T}{\tau_o}=\frac{T_1+T_2}{\tau_o}=\frac{1}{2\pi}\left(\omega_o T_1+cot\,\phi-\frac{cos(\omega_o T_1-\phi)}{sin\,\phi}\cdot\varepsilon^{-\kappa T_1}\right). \tag{28}$$

Digitized by Google

The period T is hereby determined as a function of T_1, and therefore this last quantity must be determined, which is done by solving the transcendental equation (26). In order to obtain an idea of the necessary accuracy with which this equation must be solved, we will calculate the differential quotient of T with regard to T_1, that is

$$\frac{dT}{dT_1}=1+\frac{1}{\omega_o \sin\phi}\cdot[\kappa\cos(\omega_o T_1-\phi)+\omega_o\sin(\omega_o T_1-\phi)].\varepsilon^{-\kappa T_1} \quad (29)$$

which, by using (26), can be written as

$$\frac{dT}{dT_1}=\frac{\kappa}{\omega_o}\cdot\frac{\cos(\omega_o T_1-\phi)}{\sin\phi}\cdot\varepsilon^{-\kappa T_1} \quad (30)$$

where the last factor is less than 1, so that

$$\frac{dT}{dT_1}\leq\frac{\kappa}{\omega_o}=\frac{\delta}{2\pi}. \quad (31)$$

Accordingly no very minute determination of T_1 is necessary.

For $\kappa=0$, equation (26) is satisfied by $\omega_o T_1=\pi+2\phi$, and we therefore put

$$\omega_o T_1=\pi+2\phi+\beta, \quad (32)$$

in consequence of which (26) can be written as

$$\cos\beta+\sin\beta\cdot\cot\phi=\varepsilon^{\frac{\kappa}{\omega_o}(\pi+2\phi+\beta)} \quad (33)$$

Generally β will be small, and if so (33) takes the form

$$\beta=(\pi+2\phi)\cdot\frac{\kappa}{\omega_o}\cdot\tan\phi, \quad (34)$$

where the square and higher powers of β and $\frac{\kappa}{\omega_o}$ have been neglected. In the derivation of (34) it is further assumed that $\frac{\kappa}{\omega_o}\tan\phi\ll 1$. As $\tan\phi$ can assume large values, this term must be specially examined. We have

$$\frac{\kappa}{\omega_o}\cdot\tan\phi=\frac{1}{k}\frac{R}{2\varrho}.$$

We will find later that the B-theory can be employed only when $k>\sqrt{6\frac{R}{\varrho}}$, and inserting this value in the above equation we obtain

$$\frac{\kappa}{\omega_o}\cdot\tan\phi<\frac{1}{2}\sqrt{\frac{R}{6\varrho}}=\frac{1}{6}\sqrt{\frac{\delta}{2}}. \quad (35)$$

Digitized by Google

The value of β as determined by (34) gives, therefore, in general a sufficiently close determination of T_1.

In consequence of (28), we have

$$\omega_o T = \omega_o T_1 + \omega_o T_2 = \omega_o T_1 + cot\,\phi + \frac{cos\,(\phi+\beta)}{sin\,\phi} \cdot \varepsilon^{-\kappa T_1} \tag{36}$$

Using (32) and (34), we obtain from (36) the following approximate formula for T:

$$\omega_o T = \pi + 2\phi + 2\,cot\,\phi - (\pi + 2\phi)\frac{\kappa}{\omega_o} \cdot cot\,\phi,$$

and correspondingly

$$f = \frac{T}{\tau_o} = \frac{1}{2} + \frac{\phi}{\pi} + \frac{1}{\pi}\,cot\,\phi - \left(\frac{1}{2} + \frac{\phi}{\pi}\right)\frac{\kappa}{\omega_o}\,cot\,\phi, \tag{37}$$

or approximately

$$f = f_o - k\frac{R}{2\rho}, \tag{38}$$

so that f in practice differs only slightly from f_o which is shown in Figure 10.

For the value of $g = \frac{I}{I_o}$ we find, after some calculations, the following approximate formula:

$$g^2 = \frac{\frac{1}{sin\,\phi}\left(\frac{\pi}{2} + \phi - \frac{1}{2}\,sin\,2\phi + (\pi + 2\phi)\frac{\kappa}{\omega_o}\,tan\,\phi\right) + 2\,cot\,\phi\left(1 - \frac{\kappa}{2\,\omega_o}(\pi + 2\phi)\frac{1}{cos^2\phi}\right)}{\pi + 2\phi + 2\,cot\,\phi - \frac{\kappa}{\omega_o}(\pi + 2\phi) \cdot cot\,\phi}$$

$$= \frac{\frac{\pi}{2} + \phi + \frac{1}{2}\,sin\,2\phi}{2\pi f\,sin^2\phi} = \frac{(1+k^2)\left(\frac{\pi}{2} + \phi\right) + \frac{1}{k}}{2\pi f} \tag{39}$$

This equation is quite analogous to (12), so that g can be determined with sufficient accuracy from the curve shown in Figure 11. It appears that the numerator of (39) is exactly the same function of $sin\,\phi = \frac{I_o}{I_m}$ as for $R=0$. According to (38), f is very nearly equal to f_o, and consequently the following approximate formula, analogous to (14), holds good for g:

$$g = \left(2 - \frac{I_o}{I_m}\right)\sqrt{\frac{1}{2}}. \tag{40}$$

Digitized by Google

c. THE PARAMETER k.

In the preceding, we have introduced a parameter k,' and assumed this parameter to be small—at least smaller than 1. If the constants of the arc-circuit are given, the B-theory itself does, however, put a limit to the value of k. This is easily seen thus: The condition for using Barkhausen's simple characteristic—or, put otherwise—a condition for producing oscillations of the second type is, according to the B-theory, that the arc current drops to zero, i. e., that the first minimum value of the arc current, $I_{1,min}$ is $\leqq 0$. With sufficiently close approximation, we can put

$$I_{1,min}=I_o+I_m\cdot\varepsilon^{-\kappa t}sin\left(\omega_o t-\phi\right),\tag{41}$$

where $\omega_o t$ is given the value $\phi+\frac{3}{2}\pi$, which, inserted in (41)' gives

$$I_{1,min}=I_o-I_o\sqrt{1+k^2}\cdot\varepsilon^{-\frac{R}{2\varrho}\left(\frac{3}{2}\pi+\phi\right)}\tag{41$_1$}$$

Having that $I_{1,min}\leqq 0$, we get

$$1+k^2\geqq\varepsilon^{\frac{R}{\varrho}\left(\frac{3}{2}\pi+\phi\right)}\tag{42}$$

The exponent in this expression always being small, we may write (42) as

$$k=\geqq\sqrt{\left(\frac{3}{2}\pi+\phi\right)\frac{R}{\varrho}}.\tag{42$_1$}$$

A condition for the use of the simple characteristic is therefore that, with sufficient accuracy for this purpose

$$k\geqq\sqrt{6\frac{R}{\varrho}}\tag{43}$$

In consequence whereof, the ignition potential difference must satisfy the following relation:

$$E_s\geqq I_o\left(\sqrt{6\varrho R}+\frac{1}{2}R\right).\tag{44}$$

The relations derived from the B-theory in this part of the paper have all been of a merely formal nature. In the following part, we shall examine whether the relations obtained agree with experimental results as far as the Poulsen arc is concerned.

Digitized by Google

4. Comparison of the Consequences of the B-theory with Experimental Results

We found previously that the parameter k, according to (43) must be larger than $\sqrt{6\frac{R}{\varrho}}$. If, for example, we put $R=5$ ohms and $\varrho=60$ ohms, we obtain $k>0.71$, which according to Figure 11, corresponds to $g>0.83$; while g for the Poulsen arc actually is very nearly equal to 0.71. To this experimentally obtained value of g correspond, in consequence of the B-theory, very small values of k, at any rate not greater than 0.15, since g for larger values of k, according to that theory, diverges rapidly from the value $\sqrt{\frac{1}{2}}$. *As, however, the application of the B-theory determines a minimum value of k which is much larger, that theory is not in harmony with the experimental results.*

The B-theory requires further that the "striking" or ignition voltage of the arc is at least equal to the value of E_s as determined by (44); but on measuring the maximum voltage across the arc by means of a micrometer spark gap—in series with a small condenser so as to avoid short circuiting—much smaller values are found. Thus for $I_0=20$ amperes, $R=3$ ohms, and $\varrho=400$ ohms, to which, according to (44), corresponds an $E_s=1{,}730$ volts, a spark gap as small as 0.01 mm. (0.0004 inch) was needed in order to obtain regular sparking. The gap was exposed to ultra-violet light from an arc. Consequently the maximum voltage is nearly the same as the critical voltage, that is, about 380 volts. The normal voltage for striking the arc is, therefore, far below the value found above, namely 1,730 volts, a fact also verified later on. This applies to the normal Poulsen arc with a normal distance between the electrodes which is nearly equal to the minimum critical distance (see section 2a). If the distance is increased as much as possible, the spark length increases up to 0.14 mm. (0.0057 inch) under the said conditions. This corresponds to a striking voltage of about 1,100 volts, which is considerably nearer the requirements of the B-theory, and later on we will see that the conditions existing when excessive arc lengths are used are in accordance with the B-theory.

5 a. Reasons Why the B-Theory is not Applicable to the Poulsen Arc

The foregoing discussion shows that the B-theory does not apply to the normal Poulsen arc. On the other hand, there can be no doubt that the two most pronounced features of the

Digitized by Google

characteristic shown in Figure 7—the comparatively high ignition voltage and the low voltage while the arc is burning—are essentially in agreement with the actual conditions. But there is a third feature of the arc phenomenon, which is missing in Barkhausen's simple characteristic, namely: the comparatively high voltage across the arc during the extinction. The simple characteristic of Barkhausen presupposes that the arc is extinguished on the lower voltage which exists while the arc is burning; but it is well known that this is not the case. The voltage during the extinction is often considerably higher (see, for example, A. Blondel[12]). When Barkhausen omits any reference to the extinction voltage, his motive is, no doubt, to simplify his characteristic. On the other hand, such an ideal characteristic is of value only if the results derived by means of it are in fair agreement with the actual conditions. *For the normal Poulsen arc, we have shown this not to be the case; and it will appear from the following that the reason why is that the extinction voltage is of very great importance in connection with the action of the normal arc generator.* It will also be shown that the Barkhausen characteristic, under certain circumstances, represents the actual conditions with a good degree of approximation; but these circumstances, tho often present during laboratory experiments, are never to be found in the normal Poulsen arc.

b. Extinction of the Arc

We will now examine the conditions in the arc during extinction. In Figure 13, the curve *abcde* represents the current thru the arc, assuming this to be struck at *a*, and thereafter burning on the constant voltage E_b. The equation for this current curve is then

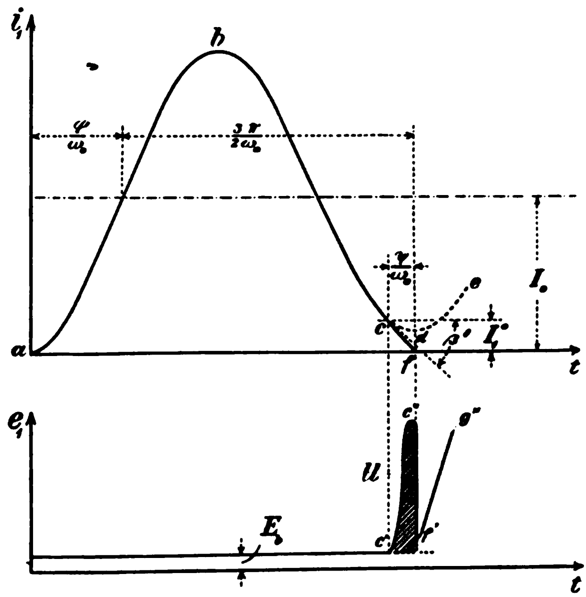
$$i_1 = I_o + I_m \varepsilon^{-\kappa t} \sin(\omega_o t - \phi). \tag{45}$$

In this case, where the arc current does not fall quite to zero, according to the B-theory, the current curve would continue past the point *d* as a damped harmonic oscillation gradually dying out, the arc current becoming fairly constant until the magnetic field extinguishes the arc again and a new oscillating discharge takes place.

The conditions are, however, somewhat different in reality. When the arc current has decreased to a certain low value I_1^o—in Figure 13 assumed to be at the point *c*—the voltage across the arc will commence to increase noticeably. The consequence of this is a more rapid dropping of the current than the curve *cd*

Digitized by Google

indicates, and the more the current decreases, the more the voltage rises in consequence and the steeper in turn becomes the drop of the current curve. If the arc current decreases at all to the value I_1^o, whereby the voltage at extinction com-



$k \cdot 0.1$

FIGURE 13—Conditions for the Extinction of the Arc

mences to influence it strongly, the result will generally be that the arc is extinguished. We will now deduce the conditions for a drop in the arc current to a value of $I_1^o = a I_o$ or less. where $a \ll 1$. The condition for this is

$$1-\sqrt{1+k^2}\cdot \varepsilon^{-\frac{R}{2\varrho}\left(\frac{3}{2}\pi+\phi\right)} \leqq a,$$

or

$$(1-a)^2 \cdot \varepsilon^{\frac{R}{\varrho}\left(\frac{3}{2}\pi+\phi\right)} \leqq 1+k^2. \tag{46}$$

For the normal Poulsen arc a will always be a comparatively small quantity, and as usual $R \ll \varrho$. From (46) we can, therefore, derive the following approximate formula:

$$\frac{R}{\varrho}\left(\frac{3}{2}\pi+\phi\right) \leqq 2a+k^2. \tag{47}$$

Digitized by Google

Here ϕ is a little less than $\frac{\pi}{2}$, while k^2 generally is considerably less than $2a$. Equation (47) can, therefore, be replaced with sufficient accuracy for the present purpose by

$$3\frac{R}{\varrho} \leqq a \quad \text{or} \quad I_1^o \geqq 3 I_o \frac{R}{\varrho} \tag{48}$$

According to (48) the extinction voltage must necessarily commence exerting its influence when the arc current has decreased to a value larger than—or at least equal to—$3 I_o \frac{R}{\varrho}$. *Only when this is the case will the arc extinguish once for every period, and only then will regular and continuous radio frequency oscillations be obtained.*

c. Integral Value of Extinction Voltage. Determination of its Minimum Value

It is even more important to examine what integral value the extinction voltage must at least assume in order to blow out the arc, when by the integral value is meant $U = \int (e_1 - E_b)\,dt$, where the integral is extended over the entire time it takes to blow out the arc. We do, however, meet here the difficulty that the law according to which the extinction voltage varies is unknown; and, as the experimental determination of it is very difficult, we cannot consider it on this occasion. Since, however, the main object is to reach a qualitative understanding of the phenomena, we will proceed so that we determine the smallest value which U can assume under the given circumstances. For this purpose we commence by determining the angle β which the tangent forms with the axis of abscissas at the point c. Using the symbols as in Figure 13 and with $\omega_o t = \frac{3}{2}\pi + \phi - \psi$, we have

$$\tan\beta = -\left(\frac{d i_1}{d t}\right)_{\omega_o t = \frac{3}{2}\pi + \phi - \psi} =$$

$$-\omega_o I_o \sqrt{1+k^2}\left(\sin\psi - \frac{R}{2\varrho}\cos\psi\right)\varepsilon^{-\frac{R}{2\varrho}\left(\frac{3}{2}\pi + \phi - \psi\right)} \tag{49}$$

At the point c the value of the arc current is

$$I_1^o = I_o\left(1 - \sqrt{1+k^2}\cos\psi\,\varepsilon^{-\frac{R}{2\varrho}\left(\frac{3}{2}\pi + \phi - \psi\right)}\right). \tag{50}$$

At this point c (Figure 14), where the arc current has the value I_1^o, the current decreases with the velocity

$$\frac{d i_1}{d t} = \tan\beta.$$

Digitized by Google

Between the voltage across the arc and the condenser voltage we have, according to (4), the following relation

$$e_1 = e - L\frac{d\,i_1}{d\,t}, \tag{51}$$

where we do not consider the voltage drop caused by the resistance of the radio frequency circuit, as this is unimportant.

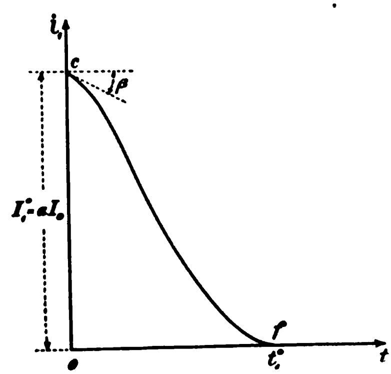


FIGURE 14—Current Curve during the Extinction of the Arc

As the blowing out of the arc commences just at the point c, we have (Figure 14)

$$(e_1)_{t=0} = E_b = (e)_{t=0} - L\,tan\,\beta. \tag{52}$$

We assume now, for the sake of simplicity, that $a = \frac{I_1^o}{I_o}$ is so small a quantity that we can, with sufficient accuracy, consider the current charging the condenser to be constant and equal to I_o, during the entire time taken to extinguish the arc. With the normal Poulsen arc, this is practically the case. The voltage across the condenser while the arc extinguishes is then determined by

$$e = (e)_{t=0} + \frac{I_o}{C}\,t, \tag{53}$$

and consequently we have

$$e_1 - E_b = \frac{I_o}{C}\,t - L\left(\frac{d\,i_1}{d\,t} - tan\,\beta\right), \tag{54}$$

and
$$U = \int_o^{t_1^o}\left(e_1 - E_b\right)d\,t = \frac{1}{2}\frac{I_o}{C}\,t_1^{o2} + L\,t_1^o\,tan\,\beta + L\,I_1^o. \tag{55}$$

Digitized by Google

where t_1^o is the time taken to extinguish the arc. From (54) it is seen that U is dependent only on the conditions when the extinction begins, the time this lasts, and finally the constants of the radio frequency circuit; while independent of the degree of progress of the extinction.

U will have the least possible value for

$$t_1^o = -\frac{1}{\omega_o^2 I_o} \cdot \tan\beta, \tag{56}$$

and

$$U_{min} = L I_1^o - \frac{1}{2} \frac{L}{\omega_o^2 I_o} \tan^2\beta. \tag{57}$$

If, inserting herein the values of $\tan\beta$ and I_1^o, given in (49) and (50), and also assuming—which is the case in practice—that 1) $k^2 \ll 1$, 2) ψ is so small a quantity that, with sufficient accuracy, we can put $\sin\psi = \psi$ and $\cos\psi = 1 - \frac{\psi^2}{2}$, 3) $\psi \gg \frac{R}{2\nu}$, we obtain this simple approximate formula for U_{min}:

$$U_{min} = \frac{1}{\omega_o} I_o R \left(\frac{3}{4}\pi + \frac{\phi}{2}\right), \tag{58}$$

or, as ϕ is slightly less than $\frac{\pi}{2}$, we obtain, with sufficient accuracy,

$$U_{min} = \frac{3}{\omega_o} I_o R. \tag{59}$$

At the same time, we obtain for t_1^o the approximate value

$$t_1^o = \frac{\psi}{\omega_o}. \tag{60}$$

The least average rise in voltage P during the extinction is therefore determined by

$$P = \frac{U_{min}}{t_1^o} = \frac{3}{\psi} \cdot I_o R. \tag{61}$$

6. Outline of the Working Principles of the Poulsen Arc

We shall now deal with the conditions at the moment the arc is struck; but first we must examine briefly the influence of the magnetic field on the arc phenomena and give a general outline of the working principles of the Poulsen arc.

The magnetic field drives the arc outward, the velocity increasing with increase of the intensity of the field. Not only the

Digitized by Google

arc itself, but also its bases (or craters) are travelling outward along the electrodes; but we will later find occasion to treat this question thoroly. This travelling—or blowing out—of the arc contributes largely to a rapid de-ionisation thereof. With a comparatively weak magnetic field, we obtain the case sketched in Figure 15, part *a*, where the arc is not being fully extinguished. Owing to the quick rise in the potential difference across the

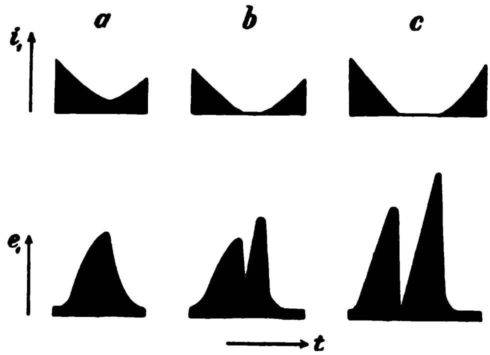


FIGURE 15—Sketch Representing the Influence of Magnetic Fields of Different Intensities on the Extinction and Re-Starting of the Arc

condenser, the voltage across the arc also rises comparatively rapidly, thereby causing the current thru the arc to increase again before it has been quite extinguished. In this case, oscillations of the 1st type are obtained; but they are quite similar to those of the 2nd type. As we will see later, this condition is rather instable.

With a somewhat stronger field, we will obtain the case sketched in Figure 15, part *b*, where the arc is being completely extinguished, but comparatively slowly, so that the voltage across the arc at the moment of extinction only drops comparatively slightly below the maximum value of the extinction voltage. While the arc is out, the arc voltage rises with the same rapidity as the voltage across the condenser, and when the voltage has reached a certain value, the arc is lit again. *By choosing small distances between the electrodes*—and such are, as we shall see later, always used in practice—*the maximum ignition (or striking) voltage needs not be much higher than the maximum extinction voltage. The de-ionisation is, of course, more pronounced at the moment of lighting (or striking) than at*

Digitized by Google

the moment of extinction; but the lighting on the other hand is accomplished at a shorter arc length than the extinction, since the first takes place between the edges of the electrodes while the latter occurs some distance back on the electrodes, the arc being driven from the first to the second position by the magnetic field.

With the field further increased we obtain the case shown in Figure 15, part *c*, where the arc is blown out so rapidly that the arc voltage at the moment of extinction drops very considerably, perhaps becoming reversed. It rises again, with the same rapidity as does the voltage across the condenser, until the ignition (or striking) voltage is reached. As the period of extinction in this case lasts a little longer, the ignition voltage must be somewhat higher than the extinction voltage; tho not very much more if the distance between the electrodes is short. The stronger magnetic field does, however, effect a very pronounced doubling of the voltage curve, thus producing two peaks of which the second one is slightly—but only slightly—higher than the first one.

The view here set forth does—as may be noticed—diverge considerably from the one we summed up above as the B-theory. This latter theory directs attention only to the ignition voltage and the conditions connected therewith. According to the B-theory, the efficiency of the arc generator is dependent mainly on a high ignition voltage, and an explanation of the means provided by Poulsen for increasing the efficiency of the Duddell arc is attempted from the point of view that these improvements tend to increase the ignition voltage. The extinction voltage is of no consequence at all in the B-theory.

According to the view set forth by the Author, and which we will briefly call the A-theory, the postulates are almost the reverse, the assumption herein being that the arc must be able to develop the necessary extinction voltage, while the ignition voltage must be as low as possible and exceed the former only by very little.

We have shown above that the consequences of the B-theory do not agree with practically obtained results so far as the Poulsen arc is concerned; and we will now undertake to ascertain whether the A-theory does agree with practice in this respect.

7. Experimental Researches on the A-theory

a. Study of the Arc Voltage

The most direct method with which to investigate the correctness of the view here set forth is to take the voltage curve for the arc, while this acts as generator of continuous radio frequency

Digitized by Google

currents. Considering the views set forth in the beginning of this paper, I have not thought it safe to employ the method indicated by Hausrath, in which a Braun tube is used. Presumably there remains available only the Gehrcke cathode-glow oscillograph[25]. This method has the advantage that a direct oscillographic reproduction of the form of the voltage curve is obtained—not a mean curve of several million periods as with the above named. A drawback is the low intensity of the light available at a high recording speed, and this is more severely felt just at present since the most sensitive photographic plates are not on the market. Another difficulty, when using the Gehrcke cathode glow tube is that even the maximum voltage across the arc in most cases is insufficient to light up the tube. This can be overcome, however, by "polarizing" the tube thru the application of a sufficiently high, constant, additional tension. The arrangement is shown in Figure 16 where G indicates the Gehrcke tube, FP the photographic plate; and HS the rotating mirror. In series with the arc and the tube is inserted a 500 volts battery, and in order to prevent any considerable amount of direct current from passing thru the tube—which would make it "sluggish"—there are also inserted two resistances made up of incandescent lamps a large resistance LB_1 and a smaller one LB_2. The voltage required to light the tube is about 600–700 volts, and since the voltage of the arc when it is burning is only approximately 50 volts or even less, the tube will light up only during the times when the voltage of the arc is considerably higher than when it is actually burning. In order to obtain the light flashes as pronounced as possible, a condenser C_1—of 25,000 cm. (0.028 μf.)—was shunted across the resistance LB_1.

In Figure 16a are shown reproductions of some of the oscillograms taken. Portions a, c, and d show the normal appearance of these oscillograms, which—as may be noticed—fully correspond to the voltage curve shown in Figure 15c and are altogether in good agreement with the A-theory. With a somewhat weaker magnetic field, oscillograms as shown in portion e are obtained, being of the same character as Figure 15, part a. *This oscillographic investigation has thus altogether verified the views here set forth.*

b. Explanation of the Experimental Values of g and E_t

We shall now examine the above-mentioned points on which the B-theory failed, in order to ascertain whether the A-theory

Digitized by Google

is more in agreement with the experimentally obtained results. We shall first estimate the value of the maximum voltages required by the A-theory. According to (61), the mean extinction voltage is determined by

$$P = \frac{3}{\psi} \cdot I_o R.$$

We will assume here and in the following discussion that the angle ψ does not vary much in the various cases, a supposition which gains some support from the oscillograms. So

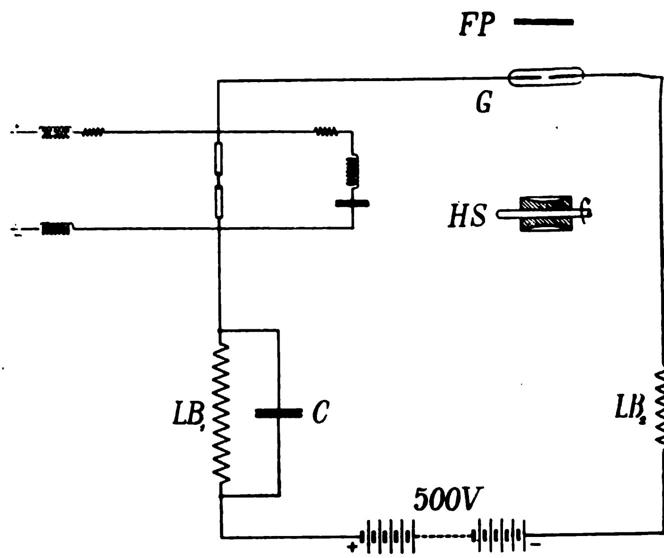


FIGURE 16—Diagram of the Gehrcke Cathode Glow Oscillograph

far as the actual value of ψ is concerned, this cannot be determined with much accuracy from the material at hand, but by estimating we have fixed it at 0.6; and thus (61) reduces to

$$P = 5\, I_o R. \tag{62}$$

For the example mentioned under heading 4, where $I_o = 20$ amperes and $R = 3$ ohms, P is therefore 300 volts. The maximum extinction voltage is, of course, somewhat higher than the mean, and the ignition voltage again somewhat higher than the extinction voltage; so that, according to the calculations, the maximum ignition voltage will probably be somewhat higher than the 380 volts as found in heading 4, but the disagreement

Digitized by Google

is, at all events, far less than with the B-theory. If we further consider that the maximum voltages are only momentary, which—according to experiment—has the effect that the values of voltage indicated by the spark micrometer are too small, even if the gap is exposed to ultra-violet light, the results of these calculations are in as near agreement with the new

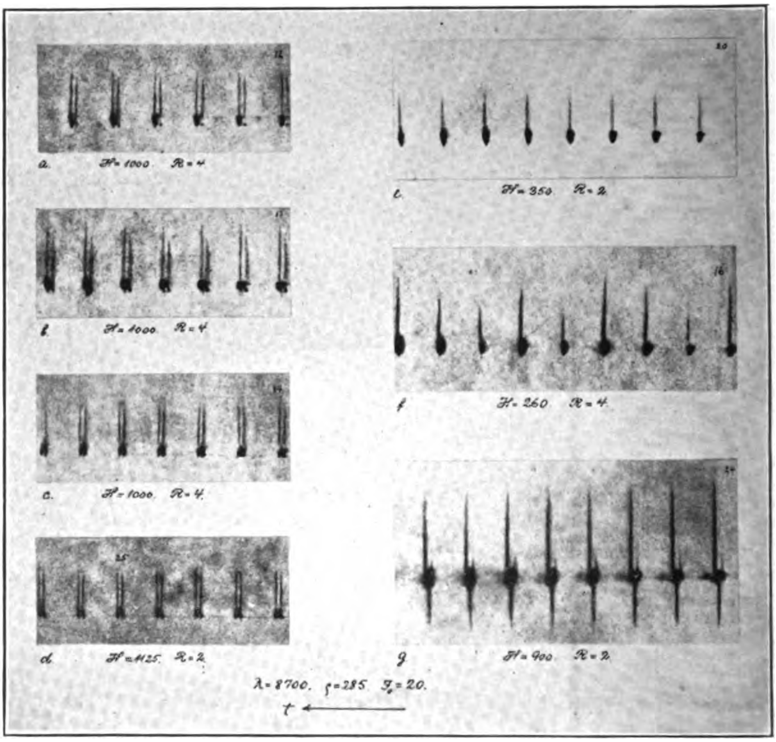


FIGURE 16a—Oscillograms of Arc Voltage Obtained with Gehrcke's Cathode Glow Oscillograph

theory as was to be expected. A determination of the maximum voltages of the arc based on the Gehrcke oscillograms did not lead to a definite result but indicated values around 300-500 volts. A full elucidation of this matter can not be expected until after a more thoro experimental and theoretical investigation of the conditions in connection with the extinction and the ignition of the arc. *But it may already be stated that the A-theory is, in the main, in accordance with the experimental results on this point.*

Digitized by Google

The next question concerns the value of g, which will be too high if determined by means of the B-theory, as this theory according to (43) demands a value of the parameter k larger than $\sqrt{6\frac{R}{\varrho}}$. This, again, is a consequence of the high ignition voltage required by the B-theory, as k and E_s are practically proportional. According to the A-theory, the ignition voltage is comparatively small, and even if the value of g according to the A-theory is not dependent on the value of k in the same manner as in the B-theory, it is, on the other hand, evident that the low ignition voltage requires a slow rise of the arc current immediately after the arc is ignited so that the current curve will be mainly a sine curve, which, at its beginning, intersects the axis at a very small angle. Accordingly, the value of g will be approximately $\sqrt{\frac{1}{2}}$. The exact, theoretical value of g can not be given at present; but it is perfectly certain to be around 0.71 as found experimentally. *The A-theory is thus in accordance with the experimental results on this point also, and provides a natural explanation of the experimentally obtained value of g.*

8. Influence of the Distance between the Electrodes on the Behaviour of the Arc Generator

As mentioned before, the distance between the electrodes in the normal Poulsen arc is comparatively small and does not differ much from the critical value. We shall now examine the result of an increase in the distance while maintaining a constant field intensity and constant supply current—the latter being done by reducing the series resistance. As the distance of separation of electrodes increases, the difference between the arc length at ignition and at extinction will become relatively less, and consequently the ignition voltage will become comparatively higher. Figure 16*a*, part *b*, shows the result of a small increase in the normal distance—about 50 per cent. By comparison with the parts *a* and *c*—both having normal distance and taken under identical conditions immediately before and after part *b*—it will be noticed that the ignition voltage already has assumed a somewhat higher value. This higher ignition voltage in turn requires a more rapid rise of current at ignition and also a steeper drop at the extinction. This latter condition results further in a reduction of the extinction voltage and a considerable drop of the arc voltage at the moment of extinc-

Digitized by Google

tion. The consequence of this is a negative arc voltage immediately after the extinction. A diagrammatic representation of these conditions is shown Figure 17, where part *a* gives the current and voltage curves for the normal Poulsen arc with the normal distance between the electrodes, while part *b* gives the same curves when the distance is larger than the normal. In case *b*, the extinction voltage is considerably smaller

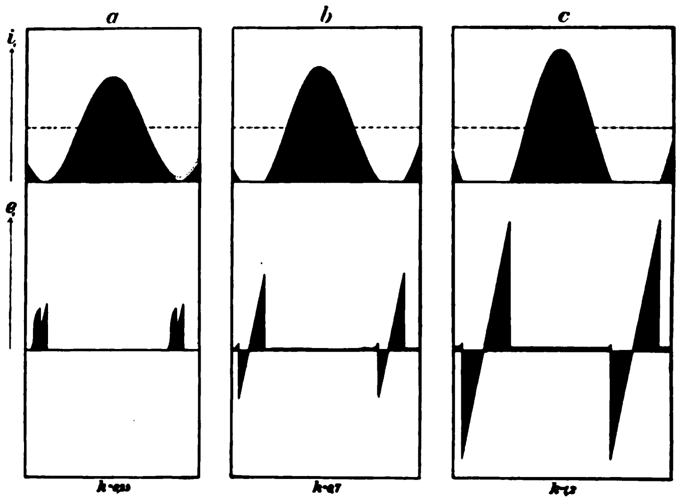


FIGURE 17—Sketch of Current and Voltage Curves for Different Distances between the Electrodes

than in case *a*; and further *b* shows quite a considerable negative arc voltage immediately after the extinction. This negative voltage will assist the de-ionization of the arc space and consequently give an increased ignition voltage. If the distance between the electrodes be further increased, these conditions will become still more pronounced, as shown in Figure 17, part *e*. The conditions are here quite in accordance with the B-theory; and this is further verified by the oscillograms shown in parts *d* and *g* of Figure 16*a*, representing the voltage curve for the arc, and taken under conditions analogous to those mentioned; but while part *d* is with normal distance between the electrodes—about 1 mm. (0.04 inch)—part *g* is with an electrode distance of 4 mm. (0.16 inch)*. When increasing the distance, the d. c.

* A voltage oscillogram with normal distance between the electrodes was taken under conditions identical with those for part *g*, but the photographic contrast was insufficient for reproduction. It did, however, fully correspond in character to the parts *a*, *c*, and *d*.

Digitized by Google

voltage on the arc is simultaneously increased—in the above case from 85 to 160 volts. With equal supply current, the latter case will give slightly more radio frequency current than with the normal distance; but in spite of this, the efficiency factor is considerably smaller than for the normal arc. The smaller efficiency for the greater distance between the electrodes is mainly a consequence of the higher voltage demanded for keeping the arc lit. The greater distance is also objectionable in other ways as the arc then is apt to blow out. The greatly increased voltage variation from the moment of extinction to the moment of re-ignition causes a correspondingly prolonged time of "charging" and a correspondingly great "frequency sensibility" of the generator. Finally the higher voltages are inconvenient from an engineering point of view. *It can thus be fully explained why the shortest possible distance between the electrodes is used with the Poulsen arc and it is also easily understood why so many of the laboratory investigations, which more or less purposely have been carried out on the basis of the B-theory have shown results having very little relation to the conditions found in practice.*

If, on the other hand, the distance between the electrodes after having been normally adjusted is diminished, maintaining the various other conditions constant, then the re-ignition on the edge of the electrodes will take place more and more easily in proportion to the decrease in distance. A state is very soon reached where the arc instead of being extinguished will carry a considerable minimum current, and the conditions will then quickly develop into a state where the arc current is constant. This is fully in agreement with the conditions mentioned under heading 2, *a*, namely, that the arc requires a certain minimum length in order to be active.

9. Influence of the Magnetic Field on the Arc

a. Photographs of the Arc

In order to get an understanding of the influence of the magnetic field, a series of experiments have been carried out, and numerous photographs of arcs and their craters have been taken by means of the arrangement shown Figure 6, which is explained previously. The pictures divide into 3 groups: 1. stationary crater pictures taken from above thru the mica window g_1, the lens B_1, and reflected from the mirror Sp_1 to the plate FP_1; 2. crater oscillograms, also taken from above, the light on the

Digitized by Google

way to the plate FP_3 passing the rapidly rotating mirror Sp_2: 3. side views of the arc, taken thru the window g_2 and the lens B_2, on the plate FP_2. In all cases, shutters were used (L_1 and L_2), giving a time for exposure of about 0.01 second. Especially those photographs mentioned under groups 2. and 3. have contributed markedly to the explanation of the behaviour of the arc in a magnetic field under various conditions.

b. Normal Crater Oscillograms

When the arc generator is normally adjusted, i. e., when the distance between the electrodes is the most suitable, and the magnetic field has the most suitable value, at least approximately, oscillograms of the type shown in Figure 17*a*, parts *a*–*d*, and Figure 17*b*, part *a* are obtained. Figure 17*b*, part a_1 is a side view of the arc corresponding to part *a*—both taken simultaneously. When printing from the photographic negative, the negative crater has been exposed somewhat longer than the positive crater, since the density of the image of the negative crater is far greater than that of the positive one. (The term "crater" is here used for the bases of the arc on both electrodes, altho no actual crater exists, at least not on the positive electrode.) Figure 17*a*, parts *c* and *d* are differently exposed portions of the same plate, showing separately certain particular features. All necessary information concerning the oscillograms and the conditions under which they are taken is found from the title and the supplementary data given in the figures. Thus, small sketches show the location of the electrodes; arrows marked *t* indicates the direction of increasing time on the oscillograms; lines marked τ denote the length of the period, and scales show the dimensions at right angles to the time axis.

Figure 17*a*, part *a* corresponds to the most suitable magnetic field under the conditions in question ($\lambda = 8{,}700$ m., $R = 1$ ohm); not much is to be seen of the negative crater as it travels mainly along the vertical end surface of the carbon; the periodic character of the negative crater is clearly seen on the original plate, but the positive is by far the most pronounced. Part *b* corresponds to a shorter wave-length (4,300 m.) and a field a little too strong. Here the oscillogram of both craters is very distinct—especially that of the positive one. Furthermore, the oscillogram of the arc itself is seen between the two crater pictures. Parts *e* and *d* represent the conditions for a wave-length of 6,000 m., and a field considerably stronger than the

Digitized by Google

most suitable one. Both of the craters and also the arc itself are here seen very clearly. In all of the three cases shown in Figure 17*a* the arc was burning in coal gas; whereas Figure 17*b*,

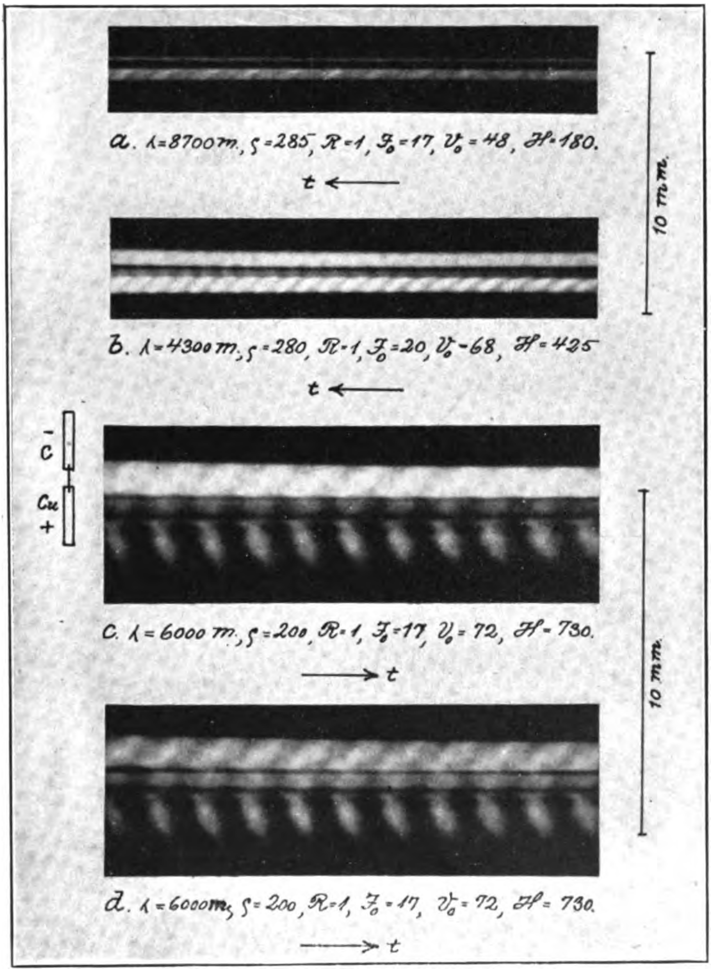


FIGURE 17a—Crater Oscillograms

part *a* shows the oscillogram of an arc in hydrogen. In hydrogen, only the violet core of the arc appears, while in coal gas this is surrounded by a greenish aureole.

It appears distinctly from the four oscillograms that the arc

Digitized by Google

is struck once in every period on or near the edges of the electrodes and is then driven outward by the magnetic field, so that the craters in the course of the period move away from the edges.

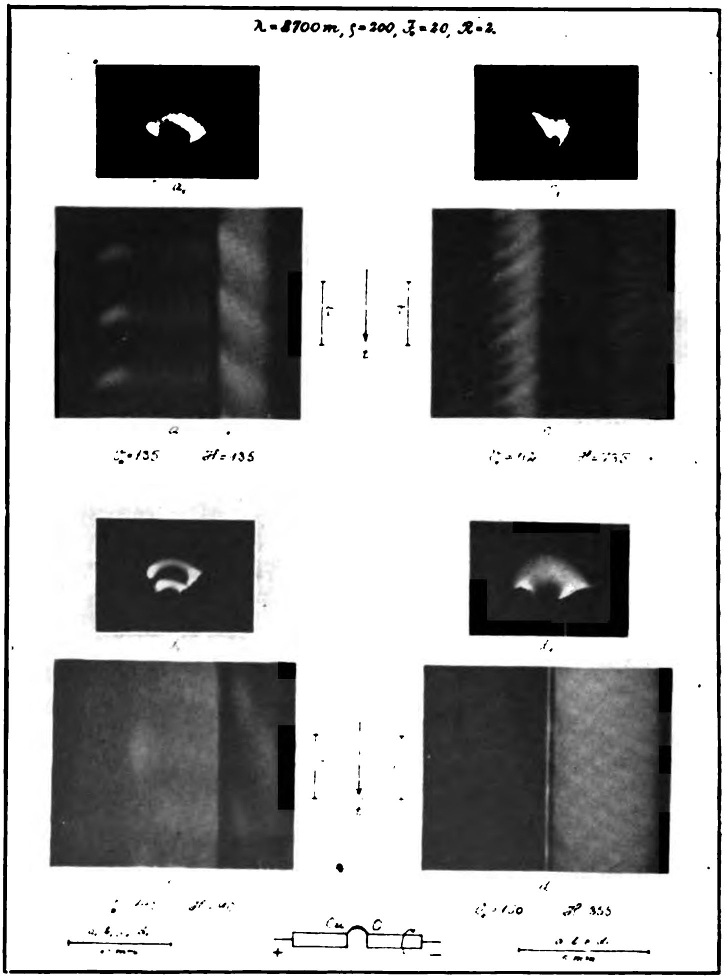


FIGURE 17b—Crater Oscillograms and Side Views. Parts a, a_1, c, c_1, d and d_1 in Hydrogen. Parts c and c_1 in Coal Gas

At the end of the period, the arc is extinguished in the outer position and re-ignites again at the edges. It is further seen that this process is repeated with much regularity.

For the purpose of a closer examination of these crater

Digitized by Google

pictures, we will determine the theoretical form of the locus of the crater image during a period. We can, however, not expect any greater conformity between the theoretical and practical results, as the cathode will always be more or less eaten away, the surface thus losing its geometrically well-defined shape, and as our knowledge with regard to the movements of an arc in a magnetic field is very deficient. Nevertheless, the said investigation will still be of some interest.

For the calculations of the velocity of the arc in the magnetic field we will assume the following: 1. the current density is the same all over a cross section of the actual arc core and is constant equal to σ; 2. the cross section having the area A maintains an unaltered shape while travelling; 3. The distance x, which the arc has travelled is determined by the equation

$$A\,p\,\frac{d^2 x}{d t^2} = \frac{1}{10} A\,\sigma\,H, \tag{63}$$

where p is the density of the arc gases.

It is certain that these assumptions are only partly fulfilled. The arc will, when travelling, not only carry along the air volume contained in the arc core (fully or in part), but also some of the surrounding air. The resulting air stream will, on the other hand, accelerate the next following arc. Furthermore, the assumption that the arc carries along the larger portion of the air contained in the arc core is merely hypothetical, and not in harmony with the ideas applied—however, under essentially different conditions—by J. S. Townsend[26], R. S. Willows[27], and Wilson and Martyn[28]. The conditions can be very complicated, at least for discontinuous discharges; as appears, for instance, from the works by D. N. Mallik[29, 30]. All of these investigations are, however, almost exclusively concerned with the conditions under lower pressures and can therefore not be applied as the basis for an investigation of the matter in hand. However, many features favor the belief that our hypothesis is, in the main, correct. At all events, the equation (63) does form the simplest possible basis for our calculations, and as our immediate object is only to obtain a representation of the conditions which is correct in the main features, we shall postpone a closer investigation till later on and make equation (63) the basis of our calculations.

We shall further simplify the calculations by assuming the arc current to be constant during a part of the period and zero during the remainder of the period. That part during which

Digitized by Google

the current is assumed to be constant we will estimate to be $\tau\sqrt{\frac{1}{2}}$.

By integration of the equation (63), we obtain the following equations provided x is measured from the point a, where the arc is lit (see Figure 18, part I), that the velocity of the arc at this point is zero, and that time is reckoned from the moment of ignition,

$$x = \frac{I_o H}{20 A p} \cdot t^2 \text{ and } \frac{dx}{dt} = v = \frac{I_o H}{10 A p} t, \tag{64}$$

where v is the velocity of the arc.

The locus of the crater image will thus be a parabola having its vertex at the point of ignition and its axis at right angles to the time axis. The crater locus terminates at a distance h from the point of striking determined by

$$h = \frac{I_o H}{20 A p} l^2 \doteq \frac{I_o H}{20 A p} \frac{1}{2} \tau^2 = \frac{I_o H \lambda^2}{36.10^{17} A p} = \frac{\sigma H \lambda^2}{36.10^{17} p}. \tag{65}$$

We shall now examine whether the value of h determined by (65) agrees with those observed. In order to apply equation (65), we must know the values of σ and p. We have tried to determine σ by measuring the cross section of the violet arc core. This determination is not very reliable, but apparently the values for coal gas and hydrogen were the same. The value may probably be put as $\sigma = 2{,}000$ amperes per sq. cm. or 12,500 amperes per sq. inch. For the determination of p, the density of the arc, the arc-temperature, must be known. In both coal gas and hydrogen this is comparatively low. The temperature has not been exactly determined; but we have estimated the density to be $\frac{1}{4}$ of the density at 0° which corresponds to a temperature of about 1100°. At the moment of ignition the temperature is surely lower, later on probably higher. The density of hydrogen at 0° = 0.00009 gm. per cc. and of coal gas = 0.00045 gm. per cc., and formula (65) then gives for hydrogen

$$h = \frac{2 H \lambda^2}{81.10^9}, \tag{66$_1$}$$

and for coal gas

$$h = \frac{2 H \lambda^2}{405.10^9}. \tag{66$_2$}$$

In the table below are given the calculated and the measured values of h for the four cases we have examined.

Digitized by Google

	h Calculated mm.	h Measured mm.	Remarks
Figure 17a, part a	0.66	0.37	Measured on the anode
Figure 17a, part b	0.38	0.45	Measured on the cathode
Figure 17a, part c	1.3	0.9	Measured on the cathode
Figure 17a, part a	1.3	1.2	Measured on the anode
Figure 17b, part c	2.7	2.0	Measured on the cathode

The measured values of *h* are, on the average, lower than those calculated; this is consistent with the fact that the arc itself is travelling a greater distance than the images of the craters which appears clearly from the side views shown. (See especially Figure 17*c*, parts *a* and *b*, and Figure 17*b*, part *b*.) When the entirely provisional character of the theory is considered, the theoretical and observed values of *h* must be admitted to agree fairly well.

From the preceding, it follows that the velocity of the arc and craters is smallest directly after the ignition, and consequently it is to be expected that the temperature of the negative crater is highest near the point of ignition. This view is confirmed by Figure 17*b*, part *a* and, tho not in so pronounced a fashion, by Figure 17*a*, parts *c* and *d*. This comparatively high temperature on the ignition point of course facilitates the reignition of the arc at this point. We have now, in the main, explained the behavior of the arc in a magnetic field under normal conditions, and we have found it in complete agreement with the outline of the A-theory given in Section 6. We shall next proceed to examine the conditions when the field is either too strong or too weak—which cases present some peculiar features of considerable interest.

c. Magnetic Field too Strong

A couple of oscillograms taken with too powerful fields are shown in Figure 17*b*, parts *c* and *d*, with coal gas and hydrogen respectively. The locus described by the crater in this case does not consist of a single curve for each period but of several, mutually parallel and parabolic curves—three such curves in part *c* and two in part *d* for each period. As it is difficult to trace these crater curves on the photograph and still more so

Digitized by Google

on the reproduction, we have drawn the diagrammatic Figure 18, part II, which gives a representation of the crater curves. We assume the arc to be lit at *a* where the velocity at first is small, but then rapidly increases owing to the strong magnetic field. The temperature of the negative crater is therefore, as mentioned above, comparatively high at *a* but drops quite rapidly as the crater travels outwards. The result of the rapidly

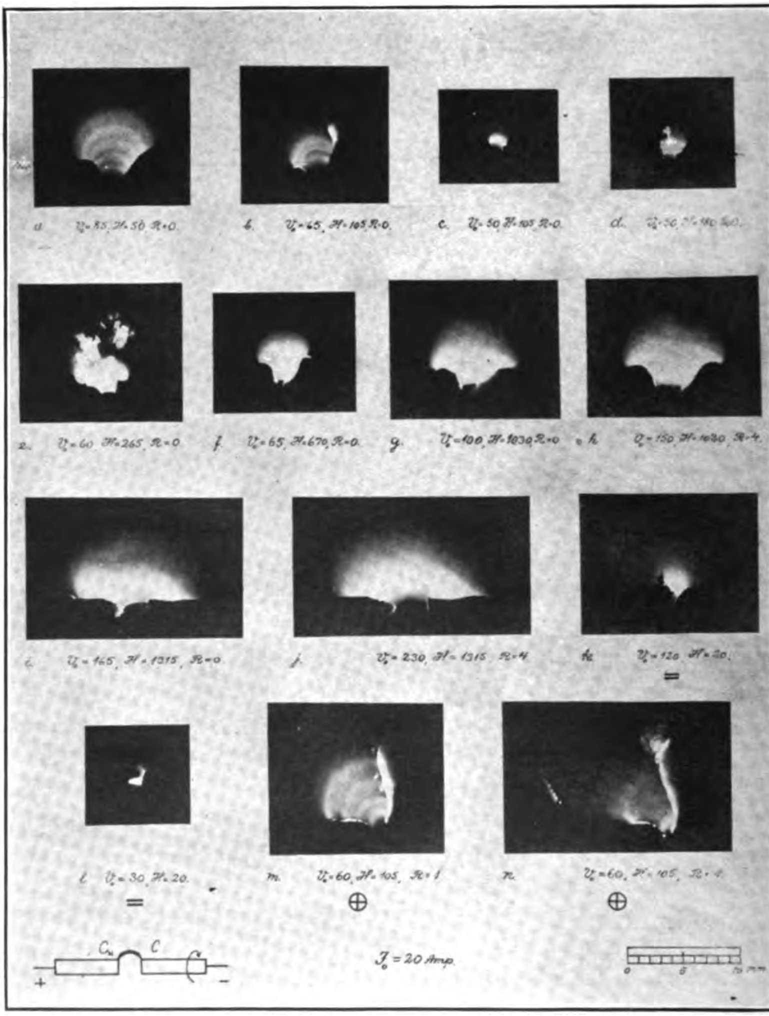


FIGURE 17c—Side Views of Arcs. For Parts *a* to *j* and *m*, *n*, $\lambda = 9000$ m. and $\rho = 200$ ohms. Parts *k* and *l* are d. c. Arcs. In Parts *m* and *n*, the Cathode Is Not Rotating

Digitized by Google

falling temperature is a rapidly increasing arc voltage, which causes a new arc to be struck at a_1 where the temperature still is comparatively high. The second arc increases at the cost of the first, which is extinguished at c. The second may eventually again be replaced by a third arc struck at a_2 and so on. *In too strong fields, there may thus exist simultaneously two or more*

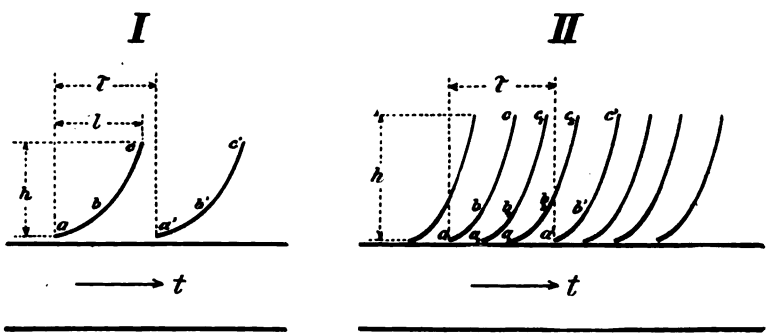


FIGURE 18—Theoretical Form of Crater Oscillograms

I. Normal magnetic field
II. Magnetic field too strong

concentric arcs between the electrodes. Toward the end of the period, when the current is small, the crater temperature decreases and the arc voltage increases to the extinction voltage after which a new arc is struck at a'. The value of the extinction and ignition voltages are about normal as will appear from the oscillograms taken, these having quite the normal appearance even with field intensities considerably above the normal (see Figure 16a, part d). The intermediate peaks on the voltage curve corresponding to the re-ignition and partial extinction at a_1 and a_2 (Figure 18, part II) are not high enough for registration by the method applied when taking the voltage oscillograms. A full elucidation of these phenomena will therefore necessitate further investigation, but there can be no doubt that the explanation given is in the main correct. Too strong a field will, of course, necessitate an increase in the supply voltage V_o—as will also be mentioned later—and consequently reduce the efficiency. *Too strong a field is therefore disadvantageous both as regards economy and constancy.*

Digitized by Google

d. MAGNETIC FIELD TOO WEAK

Too weak a magnetic field causes quite a different aspect of the arc phenomenon. The reasons are to be found in two circumstances, which are consequences of or concurrent with the magnetic field. To begin with, the arc is not completely extinguished, or, if so, only during an extremely short time. And secondly, the arc and craters travel only a very short way during a period. The combined result thereof is a marked tendency for *the arc to ignite again at—(or, if not completely extinguished, to continue from)—the point it has reached at the end of a period.* If the field is much too weak this is repeated several—and often many—times until the arc has attained such a length that the re-ignition takes place again most readily between the edges, whereupon the same succession of phenomena is started over again. These conditions are shown diagrammatically in Figure 19, where it is assumed that the arc ignites every third time on the edges. This ignition requires a considerable voltage, while the next extinction—and ignition—voltage will be comparatively small, and the next thereafter a little higher, as indicated in the figure. That the arc voltage really has this appearance is clear from Figure 16*a*, part *f*. Here the arc is struck at the edges alternately every second or third time.

The side views show a number of arcs corresponding to the various ignition points. The weaker the field is, compared with the normal field, the greater is the number of arcs (see Figure 17*c*, parts *a*, *b*, *m*, and *n*; Figure 19*a*, parts *a* and *b*; and Figure 17*b*, part b_1). *Of all these arcs only one exists at a time.*

That the above explanation is correct is very clearly verified in Figure 17*b*, part *b*, the arc in this case being distinctly seen to be ignited every second time on the edge, and thereafter some distance back on the electrode.

It is evident that *this behavior of the arc will result in an increase of the supply voltage as the potential difference required during the period of actual burning increases with increasing arc length.* The efficiency decreases, of course, when the field is too weak. At the same time, the constancy is affected. If, for instance, the arc regularly makes two "steps," two slightly varying periods are obtained. This affects the resonance possibilities of the oscillations and gives an irregular and flattened resonance curve. The conditions become still more complicated if the number of "steps" varies irregularly, and resonance curves with a "flat top" are then obtained.

Digitized by Google

In extremely weak fields, a new phenomenon appears, which we have endeavoured to illustrate in Figure 20. The arc in this case travels only a very short distance outward during each period, and continues this outward travel until the arc voltage becomes so high that a new arc is ignited at the electrode-edges. Since, however, the de-ionization in this case is comparatively small, *the outer arc will still exist after the new inner one has been*

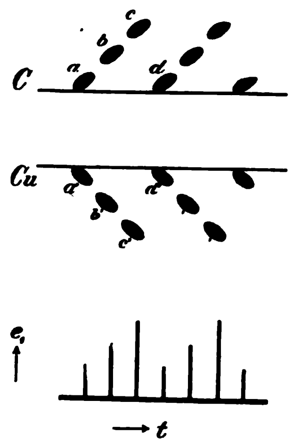


FIGURE 19—Sketch of Crater Oscillogram. Magnetic field too weak

started, and both will continue during a number of periods—the inner with increasing, the outer with decreasing current. At the same time, the electrodynamic attraction between the two simultaneously existing arcs causes the inner one to travel with a speed greater than that corresponding to the intensity of the magnetic field and the outer with a less speed. As indicated in Figure 20, the mutual attraction may more than counterbalance the action of the magnetic field, the result being that the outer arc travels inward. Such a case is seen in Figure 20*a*, part *a*, which closely corresponds to Figure 20. The conditions can be even far more complicated, as is seen in Figure 20*a*, parts *b* and *c*, *showing that a number of arcs may exist simultaneously.* This phenomenon is due to the above-mentioned conditions in very weak fields and further to the fact that the arc voltage does not drop instantly after the ignition, but remains at the high ignition voltage during a definite tho short time; or it may even

Digitized by Google

be subject to a further rise. It is a matter of course that an arc generator works very irregularly in such very weak fields.

The rôle of the magnetic field in the Poulsen arc has formerly been much discussed. (Compare the bibliography numbers 32–35, 7*b*, and 7*e*, pages 64–66.)

FIGURE 19a—Side Views of Arcs in Weak Fields. Part A in Hydrogen. Part C in Coal Gas

e. MOST SUITABLE MAGNETIC FIELD

The preceding discussion shows that the arc should burn in the weakest field, H^o, in which it works normally, only igniting once a period, and always on the electrode edges. Both stronger and weaker fields require excessive supply voltage. H^o is thus the most suitable field intensity—the one giving the highest efficiency and the most constant behavior of the arc. In order to show the connection

Digitized by Google

between V_o and H, we have taken some sets of measurements and plotted the results in Figure 21. As will be seen, V_o decreases regularly with H to a certain point (namely to the field intensity where the arc does not always strike on the edges), from which point, V_o again rises quite rapidly. The part of the curve corresponding to still smaller values of H is rather unstable, as the

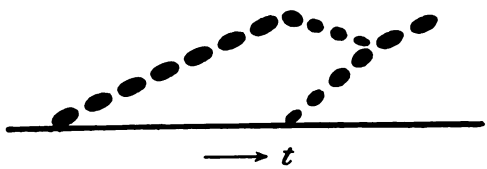


FIGURE 20—Sketch of Crater Oscillogram Magnetic Field Far Too Weak

number of "steps," and therefore also the number of arcs seen in the side view, is changed by quite insignificant irregularities; but the greater the number of arcs seen in the side view, the higher is the value of V_o. Furthermore, the lower the value of H, the greater is generally the number of arcs simultaneously seen in a side view. A regular curve cannot be drawn, but those shown do, in the main, correspond to the measurements; and at the same time they indicate the probable theoretical shape.

It thus appears that the Poulsen arc gives the highest efficiency and works with the greatest regularity at a certain field intensity H^o. On the other hand the arc may work apparently quite regularly in magnetic fields the intensities of which are considerably greater or smaller than H^o. The arc may, for example, work apparently very regularly with 2 or 3 arcs to be seen in the side view. In this case, however, the alternate periods necessarily must have slightly different lengths, and as the number of steps may vary irregularly between 2 and 3, for example, the observed frequency will also vary in an irregular manner. *In investigations on the constancy of the Poulsen arc, it is absolutely necessary to ascertain that the arc is working with the most suitable field intensity H^o*, otherwise the results will be of but little value. This point has not, so far as I know, been duly considered in any of the investigations of this kind. K. Vollmer[22], for instance, in the paper describing his interesting and careful investigation of this question, with regard to the magnetic field only remarks that the investigation is made "on an arc with transverse field." (l. c., page 150.)

Digitized by Google

The constancy of the normal Poulsen arc is so great, that a further increase in constancy would not be of any great practical value. A closer investigation is therefore deferred.

f. Appearance of the Arc in Magnetic Fields of Different Intensities

Figure 17*c* shows a series of side views taken under various conditions, especially for different values of *H*. An inspection of part *c* shows how small the arc is at field intensities near the

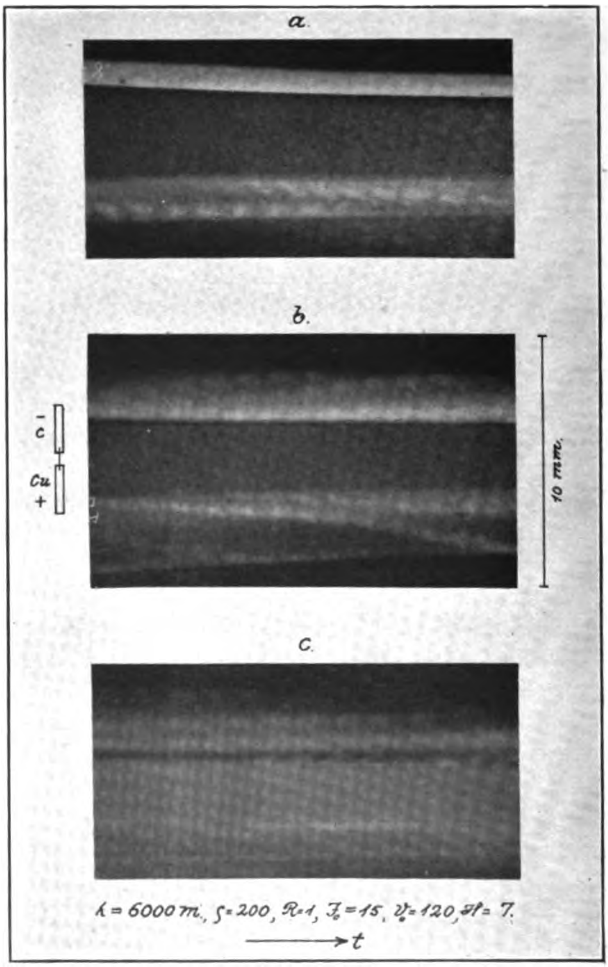


Figure 20a—Crater Oscillograms for Very Weak Magnetic Fields

Digitized by Google

most suitable one, H^o. On the other hand, part i shows how large the arc apparently is in strong fields.

A few peculiarities of arcs in coal gas may be merely mentioned. In *weak* fields a layer of *soft black* carbon is deposited on the walls of the arc chamber and tree-shaped masses of the same *soft black* carbon are deposited on the *anode*, just outside the crater as shown in part e of Figure 17c, and especially in part b of Figure 19a. In suitable weak fields, this deposition

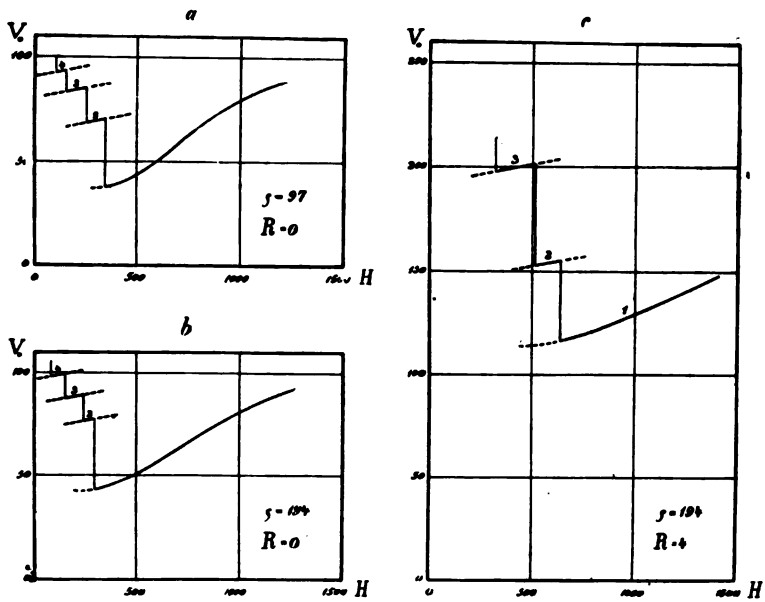


Figure 21—Relation Between Primary Voltage and Intensity of Magnetic Field for Constant Supply Current

may be so rapid that the "anode-tree" may be seen to grow. At irregular interval, these anode-trees are thrown off by the arc itself. If, with these weak fields, the *cathode* is *not* rotating, no carbon deposit is formed on the anode but instead there is formed a horn-shaped deposit of black *hard* carbon on the cathode as shown in parts m and n of Figure 17c. This "cathode horn" is so strongly coherent that when it is broken off, the cathode carbon ring is generally also broken.

In *stronger fields* very little carbon is deposited, and what little there is in this case as a *brown* rather hard powder. On the electrodes no appreciable deposit takes place in strong fields.

Digitized by Google

The explanation of these peculiarities is probably to be looked for in variations of the temperature of the arc caused by the magnetic field, but this question has not been further investigated.

10. Further Consequences of the A-theory

The above detailed investigation has given the main features of the influence of the magnetic field on the arc when used as a generator for sustained radio frequency currents. We shall now consider the consequences which, with the knowledge thus acquired, can be drawn from the A-theory with regard to the dependence of H^o upon the constants of the r. f. circuit and the strength of the supply current.

a. Influence of the Wave Length on the Most Suitable Intensity of the Magnetic Field

We will begin by investigating how H^o depends on the wave length, the supply current, and all other conditions remaining constant.

According to (62), the average value P of the extinction voltage is proportional to $I_0 R$ but otherwise independent of the constants of the r. f. circuit. The voltage of the arc during extinction will, no doubt, increase simultaneously with the velocity of the arc. This velocity is, according to (64), proportional to the period or to the wave length. All other conditions being equal, we may therefore expect P to be dependent mainly on $H^o\lambda$, but not on H and λ separately. This being the case the most suitable intensity H^o and the wave length λ will satisfy the following relation:

$$H^o \lambda = \text{constant} \tag{67}$$

A series of corresponding values of H^o and λ have been determined and the results plotted in Figure 22. It appears that the experimental values are fairly well represented by the curve shown having the equation

$$(H^o + 400)\, \lambda = 5000 \quad \text{(Gauss km)}. \tag{68}$$

The difference between (67) and (68) can be accounted for, at least partially, without difficulty. The buoyancy of the arc will, to some degree, act as an additional magnetic field. The electrodynamic forces on the arc will act in the same way.[29] Electrostatic forces will probably also act in the same way. As shown later, the value of H^o increases with increasing values

Digitized by Google

of R; the experimental values of H^o are therefore relatively too great for small values of λ. All these disturbances acting cumulatively as they do, will probably suffice to explain the difference between (67) and (68). *The theoretically deduced relation between H^o and λ is therefore confirmed.*

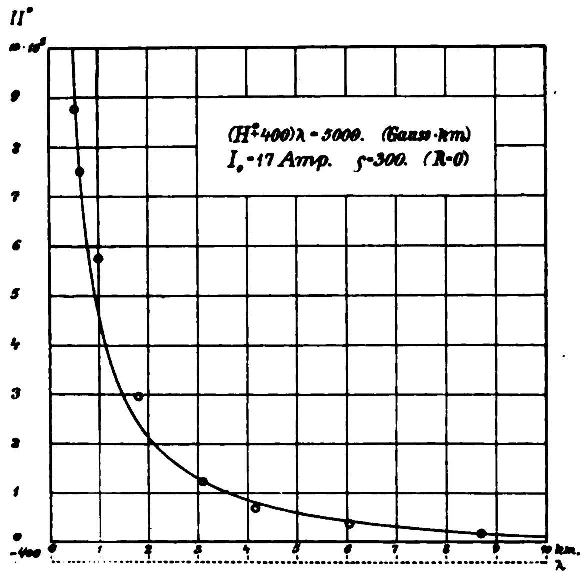


FIGURE 22—The Most Suitable Intensity of Magnetic Field as Dependent on Wave Length

b. INFLUENCE OF DENSITY OF GAS ON THE MOST SUITABLE INTENSITY OF THE MAGNETIC FIELD

The above remarks refer to the arc burning in coal gas. With the arc in hydrogen, the corresponding values of H^o are approximately 5 times smaller. This is in complete agreement with the results obtained in Section 9*c*. In this way, some well known peculiarities of the arc are easily explained. For example, working on short wave lengths, hydrogen has always been found preferable to coal gas; but at long wave lengths, sometimes hydrogen and sometimes coal gas or hydrogen more or less saturated with different hydrocarbons has been found to give the best results. The explanation is in the main simply this: *With too weak a field, it is preferable to use pure hydrogen, in too strong a field, a hydrogen compound having a greater density produces better results.*

Digitized by Google

c. H^o as Dependent on R and I_o

The next question is, how H^o depends on R, the supply current, and all other conditions being constant. According to the A-theory, the average extinction voltage P is proportional to R. (See, for example, equation (62).) We do not, however, know the exact relation between P and the velocity v of the arc at extinction; we only know that P increases with v. We are therefore unable to deduce any exact relation between H^o and R; we can only say, that H^o increases with R. The simplest supposition we can make is that P increases linearly with v. In this case H^o will also increase linearly with R. It appears from Figure 23, parts a and b, showing corresponding values of H^o and R, that H^o is really dependent linearly on R. Under the same conditions, H^o should be proportional to I_o, R and all other conditions being constant. This is confirmed by Figure 23, part c, in which are shown the values of H^o taken from Figure 23, parts a and b; the latter being reduced in the ratio of the corresponding currents, that is, in the ratio 1 to 2. The proportionality of H^o and I_o can, however, only be expected to be approximately true, since the cross section of the arc and the areas of the craters increase with increasing value of I_o. The greater these areas are, the greater in consequence must H^o be. We must therefore expect, that the (H^o, I_o)—curves will have their concavity toward the H^o—axis, a conclusion confirmed by Figure 24, showing corresponding values of I_o and H^o for different wave lengths.

11. Concluding Remarks

The theoretical deductions in Sections 9 and 10 were necessarily of a somewhat provisional nature. Their object was mainly to be an aid in the exploration of this difficult and at the same time important field. Notwithstanding this provisional nature of the A-theory, the experiments have, in the main, confirmed the conclusions drawn from that theory.

How far the A-theory is an advance over the B-theory is probably best ascertained by a consideration of the extent to which the two theories permit prediction of the influence of magnetic fields of different intensities. We have just seen that the A-theory has been quite successful with regard to this question. The B-theory, on the other hand, has not been able to throw much light on this point. The easiest way to prove this is to quote the last edition of Zenneck's excellent text book,

Digitized by Google

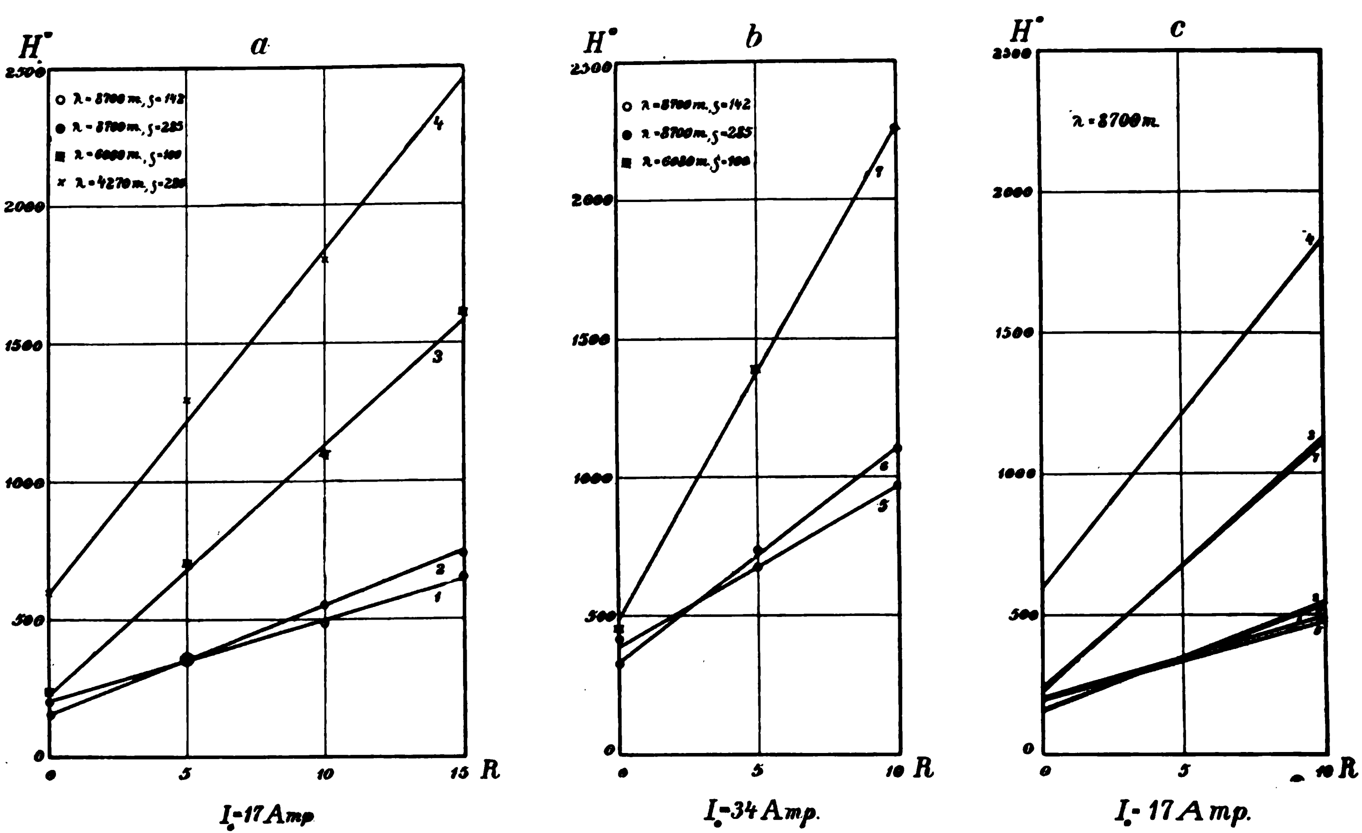


FIGURE 23—H° As Dependent On R and I_o

Digitized by Google

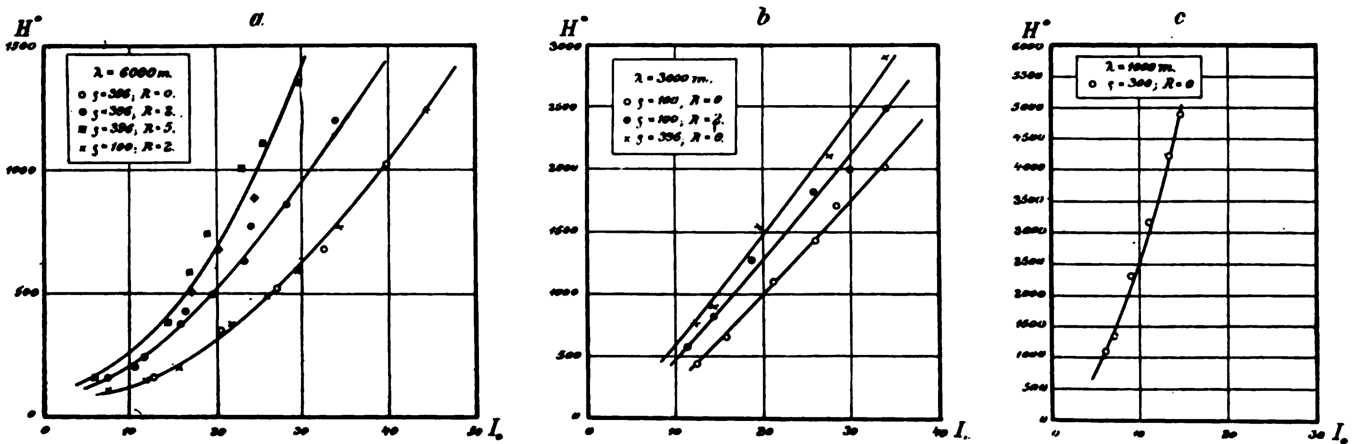


FIGURE 24—H° As Dependent On I_o for Different Wave Lengths

Digitized by Google

"Es wurde . . . darauf hingewiesen, dass ein Quermagnetfeld, das die Energie der Schwingungen sehr günstig beeinflusst, sehr ungünstig für die Konstanz der Schwingungen ist . . . Es ist dies ebenso der Grund, weshalb man mit der Stärke des Quermagnetfeldes in allgemeinen nicht sehr hoch geht, obwohl es die Energie der Schwingungen erhöhen würde." (It . . . was already pointed out that a transverse magnetic field, which is very advantageous for the energy of the oscillations, is very disadvantageous for their regularity . . . This also explains why the strength of the transverse magnetic field is in general not made very great, sacrificing a further increase in the energy of the oscillations.) (Page 244.)

The existence, in every particular case, of a certain field intensity H^o giving maximum efficiency and greatest constancy is not mentioned; to say nothing about the dependence of H^o on wave length, gas density, supply current, and r. f. resistance.

That the B-theory does not suffice to give a satisfactory explanation of the influence of the magnetic field is a natural consequence of the fact that this theory considers only the ignition voltage which, in itself, is independent of the intensity of the magnetic field; this field only influences the conditions existing while the arc is burning (and this influence, which is mainly due to the velocity of the arc, is greatest at the end of the period—i. e., at the moment of extinction). *This is the reason why the A-theory, in which the main point is the extinction voltage, gives such a simple explanation of the influence of the magnetic field.*

SUMMARY: The paper deals with an experimental investigation of the Poulsen arc carried out by means of

1. **The ordinary electrical methods of testing**
2. **Gehrcke's oscillograph for taking oscillograms of arc voltage**
3. **Photographic side views of the arc**
4. **Photographs of the arc and craters viewed in a rotating mirror, i. e., crater oscillograms.**

The chief results of the investigation are:

The experimental values of ratio between radio frequency current and the direct current are satisfactorily explained on the basis of the A-theory. This is not the case for the theory based on Barkhausen's simple characteristic. (B-theory.)

The maximum voltage across the arc is very much smaller than required by the B-theory.

For the normal Poulsen arc, the extinction voltage is almost as high as the ignition voltage.

The most suitable intensity of the magnetic field H^0 is proportional to the density of the gas and to the frequency of the oscillations, approximately proportional to the feeding current and increases linearly with the r. f. resistance.

The behavior of the arc in fields of different intensities is investigated.

Digitized by Google

BIBLIOGRAPHY

1. W. DUDDELL:

   "On Rapid Variations in the Currents thru the Direct Current Arc," "Journ. Inst. El. Eng.," Vol. 30, p. 232–261, 1901, "Electrician," Vol. 46, p. 269–273, 310–313, 1900.

2. V. POULSEN:

   Danish Patent Number 5590. ("Fremgangsmaade til Frembringelse af Vekselstrømme med højt Svingningstal.") 1902.

3. W. DUDDELL:

   a. "On the Resistance and Electromotive Forces of the Electric Arc," "Phil. Trans.," A, 203, p. 305–342, 1904.

   b. "The Musical Arc," "Electrician," Vol. 51, p. 902, 1903.

4. V. POULSEN:

   a. "System for Producing Continuous Electric Oscillations," "Trans. Int. El. Cong.," St. Louis, 1904, Vol. II, p. 963–971.

   b. "Ein Verfahren zur Erzeugung ungedämpfter elektrischer Schwingungen," "E. T. Z.," Bd. 27, p. 1040–1044, 1075, 1906.

   c. "En Metode til Fremstilling af kontinuerlige elektriske Bølger og disses Anvendelse til traadløs Telegrafi," "Fysisk Tidsskrift," Bd. 5, p. 37–52, 1906.

5. H. TH. SIMON AND M. REICH:

   a. "Tönende Flammen und Flammentelephonie," "Phys. Zeitschr.," Bd. 3, p. 278–286, 1902.

   b. "Über die Erzeugung hochfrequenter Wechselströme und ihre Verwendung zur drahtlosen Telegraphie," "Phys. Zeitschrift," Bd. 4, p. 364–372, 1903.

6. H. TH. SIMON (AND M. REICH):

   "Über die Erzeugung hochfrequenter Wechselströme und ihre Verwendung in der drahtlosen Telegraphie," "Phys. Zeitschr.," Bd. 4, p. 737–742, 1903.

7. H. TH. SIMON:

   a. "Über die Dynamik der Lichtbogenvorgänge und über Lichtbogenhysteresis," "Phys. Zeitschr.," Bd. 6, p. 297–319, 1905.

   b. "Zur Theorie des selbsttönenden Lichtbogens," "Phys. Zeitschr.," Bd. 7, p. 433–445, 1906.

Digitized by Google

c. "Über den Lichtbogen bei kleinen Stromstärken," (Nach Versuchen von H. W. Malcolm) "Phys. Zeitschr." Bd. 8, p. 471–481, 1907.

d. "Über die Wirkung des Magnetfeldes bei der Erregung ungedämpfter Schwingungen mit Hilfe des Lichtbogens," "E. T. Z." Bd. 28, p. 1232, 1907.

e. "Über ungedämpfte elektrische Schwingungen," "Jahrb. d. drahtlosen Tel.," Bd. 1, p. 16–68, 1908.

f. "Über neuere Methoden der Erzeugung elektrischer Schwingungen," "Phys. Zeitschr," Bd. 9, p. 865–874, 1908.

g. "Der elektrische Lichtbogen," (52 pp.) Leipzig, 1911.

8. H. BARKHAUSEN:

a. "Das Problem der Schwingungserzeugung," (113 pp.) Leipzig, 1907.

b. "Die Erzeugung dauernder Schwingungen durch den Lichtbogen," "Jahrb. d. drahtlosen Tel.," Bd. 1, p. 243–262, 1908.

9. G. LANGE:

"Beiträge zur Kenntniss der Lichtbogenhysteresis," "Diss. Gött.," 1909; "Ann. d. Physik," Bd. 32, p. 589–647, 1910.

10. M. REICH:

"Über Grösse und Temperatur des negativen Lichtbogenkraters," "Phys. Zeitschr," Bd. 7, p. 73–89, 1906.

11. K. W. WAGNER:

"Der Lichtbogen als Wechselstromerzeuger," (119 pp.) Leipzig, 1910.

12. A. BLONDEL:

"Sur les Phénomènes de l'Arc Chantant," "L'Eclairage Electrique," T. 44, p. 41–58, 81–104, 1905.

13. G. GRANQUIST:

a. "Über die Bedeutung des Wärmeleitungsvermögens der Elektroden bei dem elektrischen Lichtbogen.," "Nova Acta Reg. Soc. Uppsala," (56 pp.) 1903.

b. "Über die Periode und die Phasendifferenz zwischen Strom und Spannung im singenden Flammenbogen," "Boltzmann-Festschrift," p. 799–808, 1904.

c. "Zur Theorie des elektrischen Lichtbogens," "Arkiv f. Math. o. Fys.," Bd. 2, No. 17, p. 1–19, 1905.

Digitized by Google

14. J. STARK:
a. "Die Elektrizität in Gasen," (509 pp.) Leipzig, 1902.
b. "Zur Kenntnis des Lichtbogens," "Ann. d. Phys.," Bd. 12, p. 673–713, 1903.

15. J. STARK, T. RETSCHINSKY AND A. SCHAPOSCHNIKOFF:
"Untersuchungen über den Lichtbogen," "Ann. d. Phys.," Bd. 18, p. 213–251, 1905.

16. J. J. THOMSON:
"Conduction of Electricity thru Gases.," (566 pp.) Cambridge, 1903.

17. A. O. LILJESTRÖM:
"Ljusbågen som källa för elektriska svängningar," (61 pp.) Uppsala, 1908.

18. H. HAUSRATH:
"Verfahren zur Darstellung periodischer Hochfrequenzkurven mit der Braunschen Röhre," "Phys. Zeitschr.," Bd. 12, p. 1044–1046, 1911.

19. K. ORT:
"Untersuchung der Schwingungsvorgänge des Lichtbogengenerators," "Jahrb. d. drahtlosen Tel.," Bd. 6, p. 119–132, 1912.

20. H. FASSBENDER AND E. HUPKA:
"Nachweis von Schwingungen erster und zweiter Art am Poulsenbogen," "Phys. Zeitschr.," Bd. 14, p. 222–226 1913.

21. P. O. PEDERSEN:
"Beiträge zur Theorie der drahtlosen Telephonie," "Jahrb. d. drahtlosen Tel.," Bd. 5, p. 449–498, 1912.

22. K. VOLLMER:
"Über die Schwankungen der Frequenz und Intensität der Lichtbogenschwingungen," "Jahrb. d. drahtlosen Tel.," Bd. 3, p. 117–174, 213–249, 1910.

23. J. A. FLEMING:
"Some Observations on the Poulsen Arc as a Means of Obtaining Continuous Electrical Oscillations," "Phil. Mag.," Vol. 14, p. 254–265, 1907.

24. L. W. AUSTIN:
"The production of High-Frequency Oscillations from the

Digitized by Google

Electric Arc," "Bull. Bur. Stand.," Vol. 3, p. 325–340, 1907.

25. E. Gehrcke:
   a. "Eine einfache Methode zur Bestimmung des Stromverlaufs hochgespannter Wechselströme," "Verhand. Phys. Ges.," Bd. 6, p. 176–178, 1904.
   b. "Glimmlicht-Oszillograph," "Zeitsch. f. Instrumentenkunde," Bd. 25, p. 33–37, 278–280, 1905.

26. T. S. Townsend:
   "The Diffusion and Mobility of Ions in a Magnetic Field," "Proc. Roy Soc.," A, Vol. 86, p. 571–577, 1912.

27. R. S. Willows:
   a. "On the Effect of a Magnetic Field in the Discharge thru a Gas," "Phil. Mag." (6), Vol. 1, p. 250–260, 1901.
   b. "Action of a Magnetic Field on the Discharge thru a Gas," "Phil. Mag." (6), Vol. 9, p. 370–378, 1905.

28. H. A. Wilson and G. H. Martyn:
   "On the Velocity of Rotation of the Electric Discharge in Gases at Low Pressure in a Radial Magnetic Field," "Proc. Roy. Soc.," A, Vol. 79, p. 417–428, 1907.

29. D. N. Mallik:
   a. "Magnetic Rotation of Electric Discharge," "Phil. Mag." (6), Vol. 16, p. 531–550, 1908.
   b. "Theory of Electric Discharge in a De La Rive's Tube," "Phil. Mag." (6), Vol. 24, p. 500–507, 1912.

30. D. N. Mallik and A. B. Das:
   "Electric Discharge in a Transverse Magnetic Field," "Phil. Mag." (6), Vol. 32, p. 50–65, 1916.

31. W. E. Ayrton:
   "Note on the Electric Light," "Electrician," Vol. 2, p. 76, 1879. (H. Ayrton, "The Electric Arc," p. 36, London.)

32. G. Benischke:
   "Zur Erklärung der sogenannten ungedämpften Schwingungen," "E. T. Z.," p. 1212–1213, 1906; p. 69–70, 354, 1907.

33. E. Ruhmer:
   "Zur Erklärung der sogenannten ungedämpften Schwingungen," "E. T. Z.," p. 69, 1907.

Digitized by Google

34. M. Reithoffer:

"Zur Erklärung der ungedämpften Schwingungen," "E. T. Z.", p. 308–309, 1907.

35. H. R. v. Traubenberg:

"Erklärungsversuch der günstigen Wirkung des Magnetanblasung," "E. T. Z.," p. 559, 1907.

Digitized by Google

LIST OF SYMBOLS

$C=$	capacity in the r. f. circuit	(Farads)
$L=$	inductance in the r. f. circuit	(Henrys)
$\rho=\sqrt{\frac{L}{C}}=$	characteristic of r. f. circuit	(Ohms)
$R=$	effective resistance in r. f. circuit	(Ohms)
$\kappa=\frac{R}{2L}=$	damping coefficient of r. f. circuit	$\left(\frac{1}{\text{Sec.}}\right)$
$\omega_o=2\pi n_o=\frac{1}{\sqrt{LC}}=$	angular velocity of r. f. circuit when $R=0$	$\left(\frac{\text{Radians}}{\text{Sec.}}\right)$
$\tau_o=2\pi\sqrt{LC}=$	natural period of r. f. circuit when $R=0$	(Sec.)
$\omega_o'=2\pi n_o'=\sqrt{\omega_o^2-\kappa^2}=$	angular velocity of r. f. circuit when $R>0$	$\left(\frac{\text{Radians}}{\text{Sec.}}\right)$
$\tau_o'=\frac{1}{n_o'}=$	natural period of r. f. circuit when $R>0$	(Sec.)
$\delta'=\kappa\tau_o'=$	logarithmic decrement of r. f. circuit	(Numeric)
$\delta=\kappa\tau_o=$	approximate value of logarithmic decrement	(Numeric)
$T=$	period of r. f. current	(Sec.)
$\omega=$	angular velocity of r. f. current	$\left(\frac{\text{Radians}}{\text{Sec.}}\right)$
$\lambda=$	wave length of r. f. oscillation	(Meters)
$I_o=$	supply current (constant)	(Amps)
$i_1=$	instantaneous value of arc current	(Amps)
$i=$	instantaneous value of condenser current	(Amps)
$I=$	effective value of condenser current (See Figure 8)	(Amps)
$I_m=$	maximum value of condenser current	(Amps)

$$i_1=I_o+i;\qquad \frac{1}{\tau}\int_o^{\tau} i_1\cdot dt=I_o$$

$e_1=$	instantaneous value of voltage across the arc	(Volts)
$V_o=$	d. c. voltage across the arc (See Figure 8)	(Volts)

$$V_o=\frac{1}{\tau}\int_o^{\tau} e_1\cdot dt$$

$E_c=$	voltage across the arc when burning	(Volts)
$E_s+E_c=$	ignition voltage (See Figure 7)	(Volts)
$-E_a=$	greatest numerical value of reversed terminal voltage	(Volts)
$E_1^o=$	maximum value of voltage across the arc during extinction	(Volts)

Digitized by Google

$=$ integral value of extinction voltage $= \int_o^{t_1^o} (e_1 - E_c)\, dt$ (Volts × Sec.)

$=$ time of the extinction of the arc (see Figure 14) (Sec.)

$H = \frac{U}{t_1^o} =$ mean value of rise in arc voltage during extinction (Volts)

$=$ Intensity of magnetic field (perpendicular to arc motion) (Gauss)

$H^o =$ most suitable intensity of magnetic field (Gauss)

$\sigma =$ current density in arc $\left(\frac{\text{Amps}}{\text{cm.}^2}\right)$

$p =$ density of arc gases $\left(\frac{\text{Grams}}{\text{cm.}^3}\right)$

$k = \frac{E_s}{\varrho I_o} - \frac{R}{2\varrho}$; approximate value $k = \frac{E_s}{\varrho I_o}$

$g_o = \frac{I}{I_o}, f_o = \frac{\tau}{\tau_o}$ when $R = 0$

$g = \frac{I}{I_o}, f = \frac{\tau}{\tau_o}$ when $R > 0$

$a \gg b$ means "a is much greater than b"

r.f. $=$ radio (high) frequency (frequencies over 10,000 cycles per second)

Digitized by Google

DISCUSSION

Valdemar Poulsen (by letter): It is with great interest and pleasure that I have followed Professor Pedersen's investigations. Previously we had to find the most suitable magnetic field in the different cases in an empirical way. I myself have from the very first considered the influence of the magnetic field on the arc-generator as a very complicated one. I have therefore not put forth any theory with regard to this point. Not having been able to give any satisfactory explanation of the dependence of the most suitable field upon the different constants of the r. f. circuits, I have only discussed this point very sparingly in my papers.

I never found the explanations given by the Authors mentioned in Professor Pedersen's paper satisfactory. The experimental data at hand until now have been simply insufficient for the solution of this problem. Professor Pedersen has, in an admirable manner, procured the necessary experimental material, and he has at the same time given an explanation of the different phenomena in connections with the magnetic field, which, as far as I can see, is in every way satisfactory.

I wish to take this opportunity to renew my congratulation to my friend, Professor Pedersen, on this very important paper.

Copenhagen, February 2, 1917.

Leonard F. Fuller (by letter): Electrical machinery would be at a great disadvantage in commercial work if the load had to be suited to the machine available, rather than the machine being designed for the load. Likewise radio transmitters should be designed to fit the antenna available rather than by attempting to make the antenna fit the transmitter. This is quite proper, as in high power work especially, the antenna constants are always limited by considerations of cost.

I have read Professor Pedersen's paper with keen interest as it deals with the subject of arc theory with the idea of obtaining data useful in design work. The designer of arc transmitters, and especially of high power units, is constantly required to solve problems of which the following is a typical example:

Given:—Antenna $C=0.015$ μf.
Antenna $R=1$ to 3 ohms, depending on wave length.
Wave length range $=5,000$ to 20,000 meters.

Required:—Design an arc converter capable of delivering 300 amperes in the above antenna, and determine the volts and amperes of the D. C. power supply.

Digitized by Google

In the design of the arc, the predetermination of the range of required flux densities in the magnetic air gap is the calculation of major importance as this affects both the copper and steel in the unit and will have a great effect, not only upon the cost of manufacture, but also on the general characteristics and performance of the converter. Determination of size of water jackets, electrodes, insulation, etc., are problems of mechanical design.

I am very glad to see Professor Pedersen's use of the term "normal Poulsen arc," and heartily agree with him that most previous laboratory investigations published are of little value in testing the theory of the Poulsen arc converter. In fact most publications dealing with arc theory and performance give results which are of little practical utility and are frequently dangerous for the designing engineer.

No arc is a normal Poulsen arc in which the ratio of direct current to radio frequency current varies appreciably from the $\sqrt{2}$. This ratio has been checked in units operating at full load, and at overload with inputs up to 500 kilowatts. In practical work, this frequently provides a very helpful means of checking the calibration of switchboard instruments.

Professor Pedersen's method of calculating the required direct current volts and amperes involves an assumption of arc efficiency. It is preferable for the arc designer to compute what the efficiency will be from the radio frequency circuit constants given him to make his designs. In these calculations he will at the same time predetermine the required direct current volts and amperes and thus leave nothing to guess-work or assumption. Of course such calculations cannot be made without the necessary design data and performance equations which connect the various variables involved.

One additional point may be added to Professor Pedersen's comments on the appearance of the arc in magnetic fields of different intensities. A normal arc working in a magnetic field of proper strength will frequently build up hard slate-colored tits on the anode from which the arc will burn. These tits are usually obtained only with a hydrocarbon atmosphere of illuminating gas rich in carbon, or when using gasoline or kerosene. If the ordinary grades of alcohol or the more volatile liquid hydrocarbons are used they will not ordinarily appear. Their rate of growth is dependent upon anode temperature and they do not appear except upon well cooled anodes. By proper adjustment of anode cooling water these tits can be used as an

Digitized by Google

excellent protection to the anode tip proper and are a refinement in the initial adjustments of an arc which it is advisable to consider.

Pure hydrogen gas briefly mentioned by Professor Pedersen is a tempting proposition to the designing engineer, for its high molecular velocity so assists the magnetic field in "scavenging" or de-ionising the gap that, on short wave lengths especially, i. e., when the time allowed for de-ionisation is a minimum, it permits material reductions in the magnetic circuit, an expensive part of the arc. On large arcs operated on long wave lengths, but where heavy currents must be considered, the same arguments may be cited in its favor, and, in addition, there is the absence of soot deposit. This is often of assistance in the design of mechanical features of the unit.

The disadvantages of hydrogen are its explosive power and the inconvenience and cost of obtaining it. Even if produced electrolytically at the station, it necessitates distilled water and attention to the care of just that much more equipment. Obviously therefore the use of hydrogen is a means of helping the designer around certain technical difficulties and of reducing manufacturing cost at an increase in operating expenses.

Professor Pedersen's paper is of especial interest to me at this time as it deals fundamentally with the problem of predetermining arc performance. The Federal Telegraph Company has within the last year built three large arcs, the largest weighing 65 tons. I have had the pleasure of seeing the smallest of the three, a unit nominally rated at 200 K. W., operating on test up to 250 per cent. load with the direct current instruments and radiation ammeter all reading as calculated.

PALO ALTO, CALIFORNIA. March 7, 1917.

Digitized by Google

VOLUME 5 OCTOBER, 1917 NUMBER 5

PROCEEDINGS

of

The Institute of Radio Engineers

(INCORPORATED)

TABLE OF CONTENTS

TECHNICAL PAPERS AND DISCUSSIONS

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

PUBLISHED EVERY TWO MONTHS BY
THE INSTITUTE OF RADIO ENGINEERS, INC.
ONE HUNDRED AND ELEVEN BROADWAY
NEW YORK

THE TABLE OF CONTENTS FOLLOWS ON PAGE 323

Digitized by Google

GENERAL INFORMATION

The right to reprint limited portions or abstracts of the articles, discussions, or editorial notes in the PROCEEDINGS is granted on the express condition that specific reference shall be made to the source of such material. Diagrams and photographs in the PROCEEDINGS may not be reproduced without securing permission to do so from the Institute thru the Editor.

Those desiring to present original papers before The Institute of Radio Engineers are invited to submit their manuscript to the Editor.

Manuscripts and letters bearing on the PROCEEDINGS should be sent to Alfred N. Goldsmith, Editor of Publications, The College of the City of New York, New York.

Requests for additional copies of the PROCEEDINGS and communications dealing with Institute matters in general should be addressed to the Secretary, The Institute of Radio Engineers, 111 Broadway, New York.

The PROCEEDINGS of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings in New York, Washington, Boston or Seattle.

Payment of the annual dues by a member entitles him to one copy of each number of the PROCEEDINGS issued during the period of his membership. Members may purchase, when available, copies of the PROCEEDINGS issued prior to their election at 75 cents each.

Subscriptions to the PROCEEDINGS are received from non-members at the rate of $1.00 per copy or $6.00 per year. To foreign countries the rates are $1.10 per copy or $6.60 per year. A discount of 25 per cent. is allowed to libraries and booksellers. The English distributing agency is "The Electrician Printing and Publishing Company," Fleet Street, London, E. C.

Members presenting papers before the Institute are entitled to ten copies of the paper and of the discussion. Arrangements for the purchase of reprints of separate papers can be made thru the Editor.

It is understood that the statements and opinions given in the PROCEEDINGS are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

COPYRIGHT, 1917, BY

THE INSTITUTE OF RADIO ENGINEERS, INC.

ONE HUNDRED AND ELEVEN BROADWAY

NEW YORK, N. Y.

Digitized by Google

CONTENTS

Digitized by Google

OFFICERS AND BOARD OF DIRECTION, 1917

(Terms expire January 2, 1918; except as otherwise noted.)

PRESIDENT

MICHAEL I. PUPIN

VICE-PRESIDENT

JOHN L. HOGAN, JR.

TREASURER

LOUIS R. KRUMM

SECRETARY

DAVID SARNOFF

EDITOR OF PUBLICATIONS

ALFRED N. GOLDSMITH

MANAGERS

(Serving until January 7, 1920)

ERNST F. W. ALEXANDERSON

JOHN STONE STONE

(Serving until January 1, 1919)

EDWIN H. ARMSTRONG

GEORGE S. DAVIS

(Serving until January 2, 1918)

LOUIS W. AUSTIN

JOHN HAYS HAMMOND, JR.

LLOYD ESPENSCHIED

WARREN F. HUBLEY

ROY A. WEAGANT

ADVERTISING MANAGER

LOUIS G. PACENT

WASHINGTON SECTION

EXECUTIVE COMMITTEE

CHAIRMAN

LIEUT.-COLONEL GEORGE O. SQUIER
War Department,
Washington, D. C.

SECRETARY-TREASURER

GEORGE H. CLARK
Navy Department,
Washington, D. C.

CHARLES J. PANNILL
Radio, Va.

BOSTON SECTION

CHAIRMAN

A. E. KENNELLY,
Harvard University,
Cambridge, Mass.

SECRETARY-TREASURER

MELVILLE EASTHAM,
11 Windsor Street,
Cambridge, Mass.

SEATTLE SECTION

CHAIRMAN

ROBERT H. MARRIOTT,
715 Fourth Street,
Bremerton, Wash.

SECRETARY-TREASURER

PHILIP D. NAUGLE,
71 Columbia Street,
Seattle, Wash.

Digitized by Google

SAN FRANCISCO SECTION

CHAIRMAN	SECRETARY-TREASURER
W. W. Hanscom, 848 Clayton Street, San Francisco, Cal.	V. Ford Greaves, 526 Custom House, San Francisco, Cal.

H. G. Aylsworth
145 New Montgomery Street,
San Francisco, Cal.

PAST-PRESIDENTS

SOCIETY OF WIRELESS TELEGRAPH ENGINEERS

John Stone Stone, 1907–8 — Lee De Forest, 1909–10
Fritz Lowenstein, 1911–12

THE WIRELESS INSTITUTE

Robert H. Marriott, 1909–10–11–12

THE INSTITUTE OF RADIO ENGINEERS

Robert H. Marriott, 1912 — Greenleaf W. Pickard, 1913
Louis W. Austin, 1914 — John Stone Stone, 1915
Arthur E. Kennelly, 1916

STANDING COMMITTEES

1917

COMMITTEE ON STANDARDIZATION

John L. Hogan, Jr., *Chairman*	Brooklyn, N. Y.
E. F. W. Alexanderson	Schenectady, N. Y.
Edwin H. Armstrong	New York, N. Y.
Louis W. Austin	Washington, D. C.
Ferdinand Braun	Strassburg, Germany
A. A. Campbell Swinton	London, England
George H. Clark	Washington, D. C.
William Duddell	London, England
Leonard Fuller	San Francisco, Cal.
Alfred N. Goldsmith	New York, N. Y.
Guy Hill	Washington, D. C.
Lester Israel	Washington, D. C.
Frederick A. Kolster	Washington, D. C.
George H. Lewis	Brooklyn, N. Y.
Valdemar Poulsen	Copenhagen, Denmark
George W. Pierce	Cambridge, Mass.

Digitized by Google

John Stone Stone	New York, N. Y.
Charles H. Taylor	New York, N. Y.
Roy A. Weagant	Roselle, N. J.
Jonathan Zenneck	Munich, Germany

COMMITTEE ON PUBLICITY

David Sarnoff, *Chairman*	New York, N. Y.
John L. Hogan, Jr.	Brooklyn, N. Y.
Robert H. Marriott	Seattle, Wash.
Louis G. Pacent	New York, N. Y.
Charles J. Pannill	Radio, Va.
Robert B. Woolverton	San Francisco, Cal.

COMMITTEE ON PAPERS

Alfred N. Goldsmith, *Chairman*	New York, N. Y.
George H. Clark	Washington, D. C.
Melville Eastham	Cambridge, Mass
John L. Hogan, Jr.	Brooklyn, N. Y.
Alexander Meissner	Berlin, Germany
Sir Henry Norman	London, England
Wichi Torikata	Tokyo, Japan

SPECIAL COMMITTEES

COMMITTEE ON INCREASE OF MEMBERSHIP

Warren F. Hubley, *Chairman*	Newark, N. J.
J. W. B. Foley	Port Arthur, Tex.
Lloyd Espenschied	New York, N. Y.
John L. Hogan, Jr.	Brooklyn, N. Y.
David Sarnoff	New York, N. Y.

Digitized by Google

NOTE ON "THE MEASUREMENT OF RADIOTELEGRAPHIC SIGNALS WITH THE OSCILLATING AUDION"*

By

L. W. Austin

(United States Naval Radiotelegraphic Laboratory, Washington, D. C.)

I regret very much that I did not have an opportunity to take part in the discussion of my paper which appeared in the August number of the "Proceedings." In this discussion there seems to have been a certain amount of misapprehension regarding the real object of the work, for which undoubtedly the wording of the paper was in part responsible.

The primary purpose of the work was not, strictly speaking, to determine the power in the antenna with the audion circuit coupled for reception, but rather to make it possible to exterpolate the readings of the contact detector to cover the range of weak signals beyond the sensibility of the detector. As was stated in the paper, the resistance of the antenna with the contact detector coupled is the resistance used in the calculation of power, and the power itself is usually useful in our work only for calculating the strength of field produced at the receiving point by the sending station.

As the contact detector is generally accepted as a proper instrument for measuring received signals, it is only necessary to show that the audion used as described gives audibilities proportional to the square root of the deflections of the detector galvanometer. The first part of the paper shows that this proportionality exists, at least for the loosely coupled condition. A large number of experiments with a distant station sending with various antenna currents show that within the limits of experimental error, the received audibilities are proportional to the sending current, when the receiving audion is coupled to the antenna, and the observations taken as described in the Nauen-Eilvese experiments.[1]

* "Proceedings of The Institute of Radio Engineers," 5, page 239.
[1] "Journal of the Franklin Institute," 1916, page 605.

Digitized by Google

Mr. Englund's proposal of a comparison method for measuring distant signals is very attractive, and I have spent some time in attempting to carry it out experimentally, but have in the end concluded that the chances of error due to the varying interaction at different wave lengths between the circuits are even greater than in the shunted telephone method, altho the observational accuracy may be somewhat better.

On account of changes in the strength of the telephone pulses with changing resistance in the circuit, the usual law of shunts is useless[2] for calculating audibility and the only method of being reasonably sure of correct results is to make laborious calibration experiments. The difficulties are considerably greater with the telephones in the "B" battery circuit than when they are used in the circuit in parallel with the "B" battery as shown in Figure 1 of the paper.

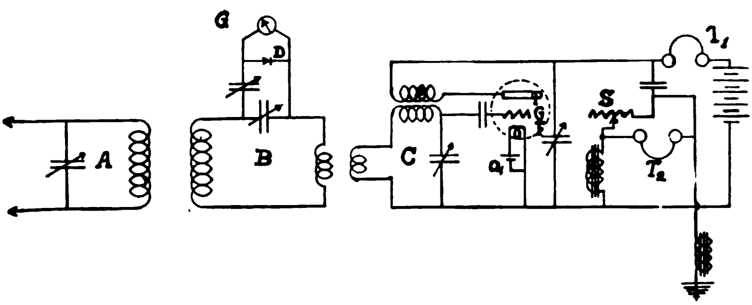


FIGURE 1

I have attempted to eliminate the variations in audion sensibility by using the same type of bulb in all the experiments, and also by having two audions ready for use, either one of which can be thrown in by a switch so that when one burns out, a new one of the same sensibility can be chosen by comparison with the one remaining.

I have recently been making experiments with the calibrated variable coupling telephone transformer, without iron, and it seems possible that the strength of signal may be measured with the variable coupling more accurately than by the shunted telephone method.

[2] Using an audibility resistance box which according to the law of shunts should be used with telephones of 5,000 ohms impedance, the best linear relation is actually obtained by using telephones of nearly 30,000 ohms impedance.

Digitized by Google

I am very ready to admit that the absolute measurements of received signals at great distances hitherto made, may very possibly be considerably in error. The subject is of such great importance scientifically, that I hope that others will take it up as soon as war conditions permit.

Digitized by Google

Digitized by Google

THE EFFECT OF COMMERCIAL CONDITIONS ON SPARK TRANSMITTER CONSTRUCTION*

By

JULIAN BARTH

(RADIO ENGINEER, MARCONI WIRELESS TELEGRAPH COMPANY OF AMERICA, ALDENE, NEW JERSEY)

A radio transmitter is essentially a generator of electromagnetic waves. A spark transmitter, in its usual form, consists essentially of an arrangement like Figure 1.

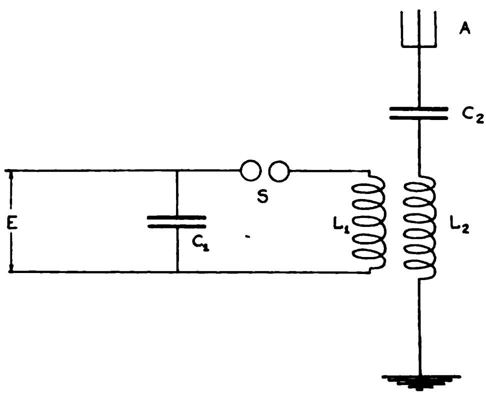


FIGURE 1—Typical Spark Transmitter

In fundamental terms, E is a source of electric energy, which charges condenser C_1 to a potential at which it causes a breakdown in spark gap S, permitting the stored energy to oscillate in the primary circuit composed of C_1, S, and inductance L_1 at a frequency determined by the constants of the circuit. The energy is transferred thru the coupled inductances L_1 and L_2 from the primary to the antenna circuit, consisting of L_2, condenser C_2 (used only for short waves), and the antenna A. This circuit, from which the energy is radiated, is tuned to the primary circuit.

* Presented before The Institute of Radio Engineers, New York, February 7, 1917.

Digitized by Google

We have here stated the fundamental action of a spark transmitter. To put to practical use these fundamental scientific ideas requires the art of radio engineering. Actual apparatus must be constructed and installed to meet varying commercial conditions, and it is this phase of radio which it is the aim of this paper to present.

In bringing up a topic of this nature, there are so many factors which might enter into the discussion that it is found desirable at once to limit the discussion to a few important conditions determining the kind of apparatus to be used for a given high note, spark transmitter installation, and furthermore, to limit it to the description of apparatus already designed and constructed by my colleagues in the Marconi Wireless Telegraph Company of America and myself, while bringing out the pertinent features bearing upon these conditions.

The chief items for consideration in planning a transmitter are

1. The nature of the traffic to be handled;
2. The available source of initial power;
3. Space limitations;
4. Permissible expenditure.

The first factor involves such factors as required distances and direction of transmission, volume of business to be handled, traffic schedules, interference, and reliability of service.

The second factor includes the requirements for the production of electric energy to charge the primary condenser. It takes into account the availability of D. C. or A. C. or the need for a prime mover as part of the apparatus.

The third factor determines simply the size of the whole transmitter and the size and shape of its separate parts.

Of the fourth factor it may well be said that it is "last but not least." It means to the engineer in his work what a man's income means to him in everyday life and requires as strict a proportioning of income and expenditure. Economy is, of course, always essential, but at times actual inexpensiveness is required; and yet at times outlay for the little niceties of operation and for symmetry and neatness is required.

Without doubt, as far as quantity manufacture goes, ship installations demand first attention. To meet this kind of business, the company has standardized installations of three kinds, two differing from each other only to a comparatively small extent, while they differ from the third quite markedly. Mr. Harry Shoemaker has minutely described, in a previous

Digitized by Google

paper,[1] the 2 and 0.5 kilowatt quenched gap sets for ship use known as types P-4 and P-5. What I have to say about them adds nothing to his description, but the way in which they illustrate good construction for the conditions met with in operation makes them fit aptly into this paper.

Figures 2 and 3 are a front and rear-side of the 2 K. W. quenched gap panel set which, with a key, antenna switch, antenna, and antenna series condenser, comprises a complete

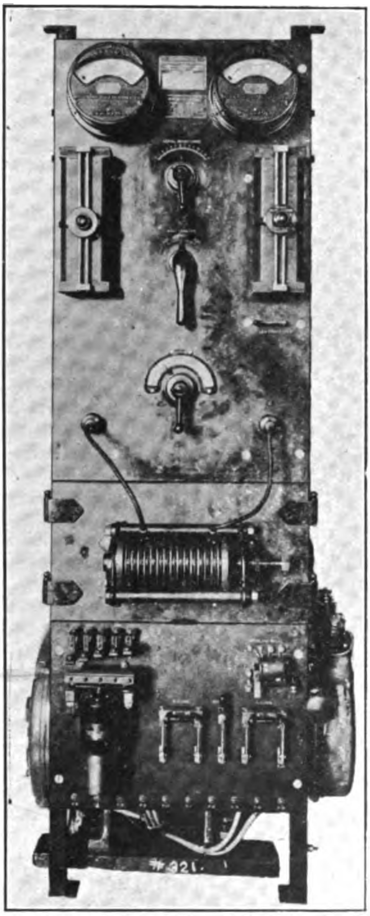


FIGURE 2—Front of Marconi Company 2 K. W. Panel Type Quenched Spark Set

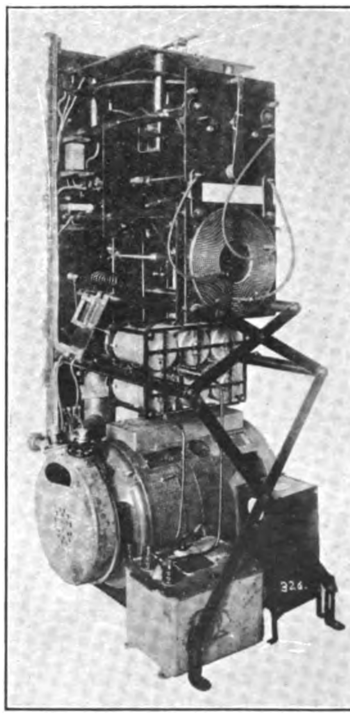


FIGURE 3—Rear and Side of 2 K. W. Panel Type Quenched Spark Set

[1] "PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS," 1916, volume 4, number 4, page 313.

Digitized by Google

transmitter. The conditions which this installation was made to meet and how it meets them follow in the order in which the factors were previously arranged:

1. NATURE OF TRAFFIC. One of the chief considerations on passenger vessels is the protection afforded by radio. For vessels crossing the ocean or making trips to South America, where distances between vessels or between vessels and coast stations may average 50 miles (80 km.), a range of a few hundred miles (or km.) will cover the zone occupied by several ships, thus providing both protection and the convenient handling of ordinary traffic. A 2 K. W., 500 cycle, quenched gap set was decided on as being able to ensure this range most economically. To ensure against the set being out of commission because of failure of the quenched gap (which is probably the least invulnerable point), a synchronous rotary gap was added with a throw-over switch enabling it to be substituted for the quenched gap during repairs to the latter. The rotary gap is mounted directly on the motor-generator; and the switch is mounted above the rotary gap, which latter also acts as a blower for the quenched gap.

The volume of traffic handled on the seas by boats within each other's range is considerable, and must all be carried on with a range of wave lengths between 300 and 600 meters. Evidently some means for minimizing interference is imperative. The set has two distinctive features and a third, auxiliary feature for effecting this. There is provided a wave changing device for instantly throwing over to any of the three wave lengths: 300, 450, and 600 meters, after the set has once been tuned. To do this, the wave length switch, located in the center of the top front panel, operates two switch arms mounted on a common shaft. These arms make contact with tap points on the primary, the secondary, and the loading coil, all of which (except the primary points, which are set in manufacturing), are set once and for all when the set is installed. Thereafter, except for slight adjustments now and then, the turning of the switch handle accomplishes a complete wave length shift. The second feature is the low power arrangement. On the front panel, just under the generator rheostat, is a switch marked "Low Power Open." When closed, it short-circuits an added resistance in the generator field; when opened, it inserts the resistance, which is of just the proper value to give a suitable field excitation when only one gap is included in the oscillation circuit. This arrangement is used when traffic is handled

Digitized by Google

between ships up to distances of 20 to 50 miles (30 to 80 km.) depending on atmospheric conditions. The whole arrangement accomplishes the purpose of getting traffic thru to nearby stations without interfering with distant ones. The third and auxiliary interference minimizer is the quenched gap, permitting of low decrements and sharp tuning, which, in conjunction with the three wave length shifts, reduces interference by two-thirds. Adding to this the power reducer cuts down interference by about 80 per cent. when all these features are handled as intelligently as they are by our modern operators.

The volume of business handled involves a necessity for speed of operation. The speeding-up is helped along by an automatic motor starter mounted on the lower front panel and controlled from the operator's bench. Merely putting the antenna switch into the "Send" position starts the motor and throws the generator field in after the machine has come up to speed. Throwing the antenna switch into "Receive" opens the generator field and sets into operation a magnetic brake on the motor, thus stopping it quickly so that the noise of running is eliminated while receiving. If the starting and stopping feature is not needed for good receiving conditions, a switch on the operator's table can short-circuit the contacts on the antenna switch which accomplish it.

2. Available Source of Power. On shipboard, D. C. at from 90 to 125 volts is the one source of power always available. Hence the method of charging the condensers, taking into account also the advantages of a 500 cycle, quenched spark transmitter, is to have a D. C. driven motor generator with low tension, 500 cycle output supplied to a high tension transformer.

3. Space Limitations. The space allotment for radio sets on shipboard is notoriously small and doors and hatchways are narrow. These are the reasons for a narrow panel arrangement of small floor space, utilizing height to as great an extent as possible. The set stands nearly six feet (2 m.) high and has adjustable extension supports to reach the ceiling of the operating room.

4. Permissible Expenditure. This set is intended for use on passenger vessels where it is open to public inspection. Hence it was considered advisable to make the set as neat as sound, rugged construction would permit. A glance at the front panel, Figure 2, will immediately impress one with its symmetry.

Digitized by Google

The finish on all parts is uniform, everything being either black dilecto or metal with a black nickel plate, except, of course, switches, which are copper. In addition, because of the volume of traffic to be handled, nicety of operation was considered more essential than low cost.

This set as a whole offers a very good example of the gigantic strides made in radio in the last few years, both as to reliability in the handling of traffic and in the organization of the manufacturing of apparatus. As a significant illustration of the latter, Figure 4 shows a few of these sets awaiting shipment.

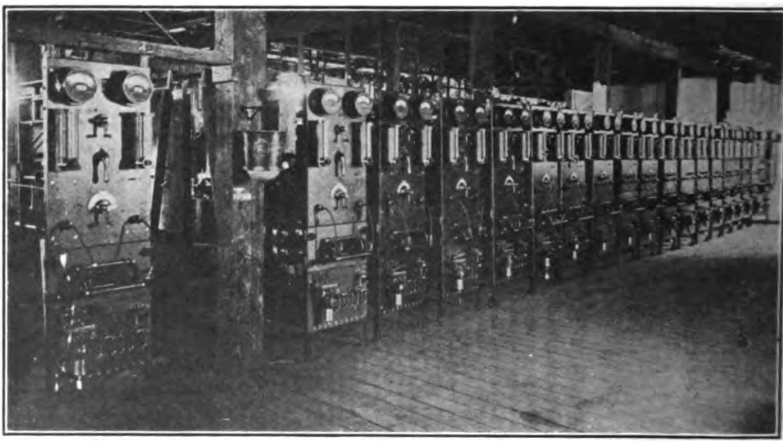


FIGURE 4—Group Manufacturing and Testing of 2 K. W. Quenched Spark Sets at Aldene Factory of Marconi Company

Figures 5 and 6 show a 0.5 K. W., 500 cycle, quenched gap set built to meet very nearly the same commercial conditions as the 2 K. W. sets. The one difference is in the nature of the traffic. The sets are intended for coastwise passenger vessels. The ships are never far from some coast station and it was therefore considered that 0.5 K. W. was ample power. The smaller set has all the features of the large set but its range is smaller, and it is naturally smaller also in physical dimensions.

The third type of ship installation is shown in Figures 7 and 8. The over-all dimensions are roughly 23 inches by 23 inches by 3 feet high (58 cm. by 58 cm. by 91 cm.). The motor-generator, rotary gap, transformer, primary reactance coil, primary condenser, and hand starter are mounted underneath

Digitized by Google

the frame; the oscillation transformer and loading coil unit (of which the primary is movable), the antenna series condenser, and the tuning indicator are mounted on top. The set is intended for use on small cargo vessels only. It differs markedly from the two other types of ship installations in two of the four

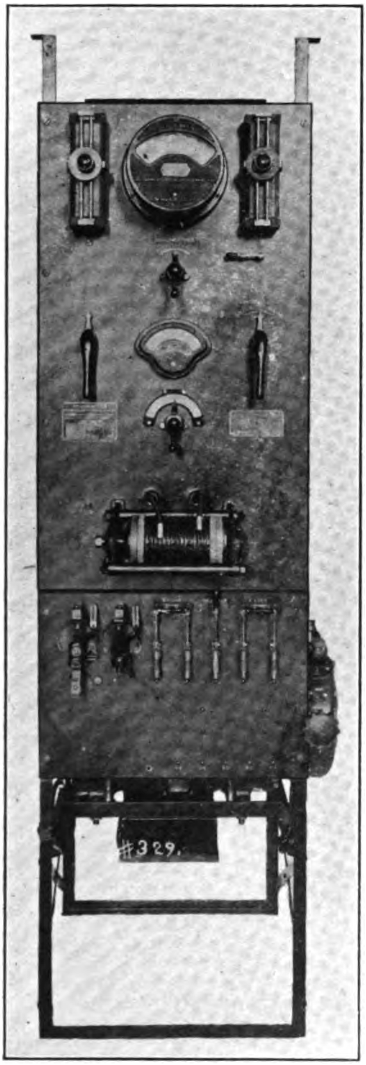


FIGURE 5—Front of Marconi Company 0.5 K. W., Quenched Spark, Panel Type Set

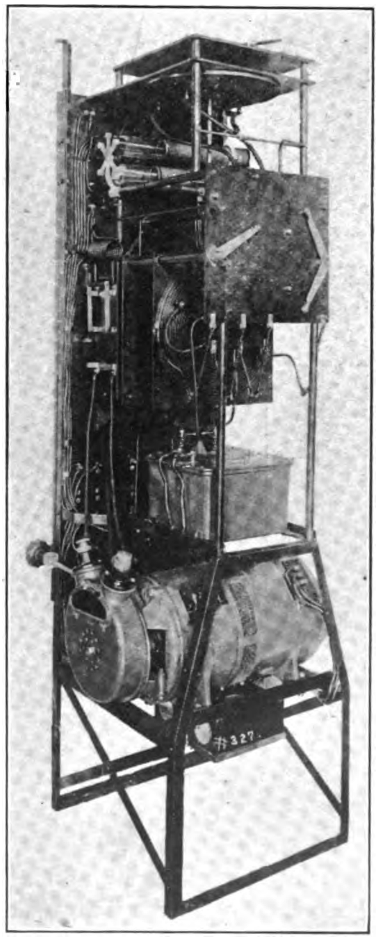


FIGURE 6—Rear and Side View of 0.5 K. W., Quenched Spark Set

Digitized by Google

factors we have been discussing, namely, the nature of traffic and the permissible expenditure. As to the nature of traffic, small cargo vessels naturally have very little traffic to handle, and such business as they do handle is not so urgent as that of passenger vessels. A power of 0.25 K. W. was considered ample for the range required. Such aids to efficient handling of a large volume of business as quick wave length shifts, very

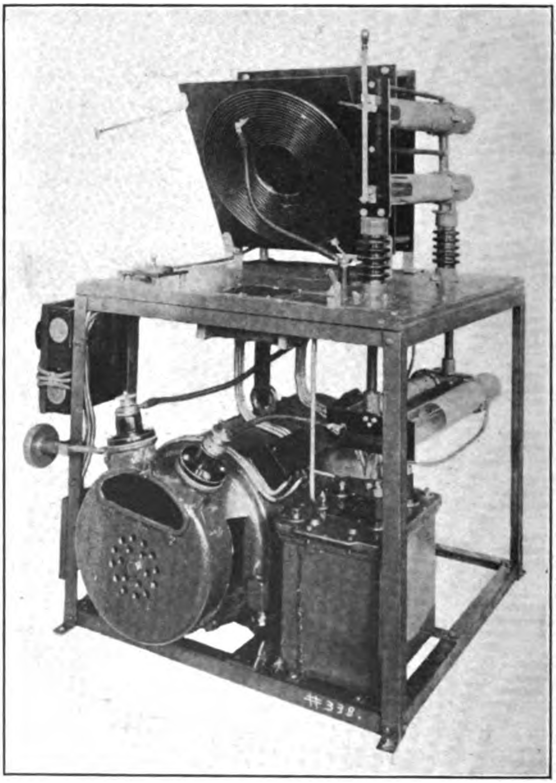


FIGURE 7—Front View of Marconi Company 0.25 K. W., Rotary Synchronous Spark, Cargo Ship Set

low power regulators, and automatic starters are not needed. There are not even the usual motor and generator rheostats. The motor speed and the power will never vary 10 per cent., and the set is not critical of adjustment for note. The only adjustment necessary is the synchronizing of the gap.

Digitized by Google

As to expenditure allowance, ruggedness and stoutness have been substituted for any attempt at beauty. There will be no passengers to view the apparatus critically; hence finish has been made of secondary importance. Actual inexpensiveness is a feature of this outfit. The more rugged rotary gap has been substituted for the quenched gap. Because of this, the

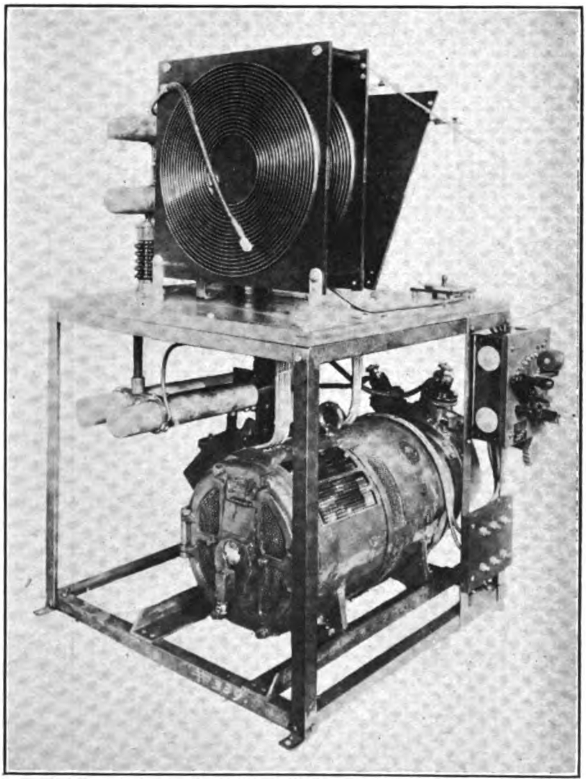


FIGURE 8—Rear and Side View of 0.25 K. W., Rotary Synchronous Spark, Cargo Ship Set

tuning is less critical, and a tuning indicator consisting of a small inductance in the ground circuit, with a small lamp shunted across a variable portion of it, is used in place of the more expensive aerial ammeter. The coupling adjustment is a simple hinged swing of the primary coil, guided and locked on a rod extending from the fixed secondary.

The set, as a whole, is a model of rugged construction at

Digitized by Google

small cost for short range work. We are building a very large number of these sets now on one order, a few of which have been completed; another example of modern manufacturing methods applied to radio.

Figure 9 is a transmitting panel whose reason for being is the second factor under discussion, namely, availability of initial power. It is built for coast station work where the only power obtainable is single phase, 60 cycle, 110 or 220 volt current. A single phase, A. C. driven motor-generator of any power gives

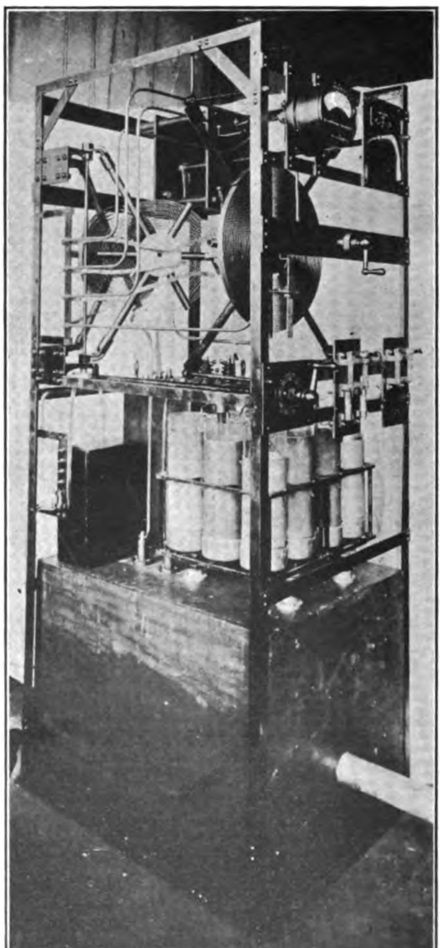


FIGURE 9—Marconi Company 3 K. W., Non-Synchronous Rotary Gap Set

Digitized by Google

poor satisfaction when it is started and stopped frequently. We have, therefore, substituted for the 2 K. W. motor-generator, quenched gap, ship sets, a 3 K. W., 1170 spark-per-second, non-synchronous gap set. The initial input and the antenna output in both cases are practically identical, the motor-generator losses about equalling the extra losses in the non-synchronous gap, giving the same over-all efficiency; but in the latter case a complete motor-generator, an exciter, and a quenched and synchronous rotary gap are saved, and in their places are a non-synchronous rotary gap, driven by a single phase induction motor, and a silencing cabinet to deaden the spark. The latter is a double walled wooden box with a 3 inch (7.5 cm.) thick lining of "tinofelt." The note obtained is not as clear and high pitched as a quenched spark note, but operators claim it is less shrill and more pleasant to read, and carries at least as far. The set has a quick shift wave length switch for quick handling of traffic just as have the ship sets. The parts, starting at the top are antenna ammeter, wave length switch, loading coil, secondary coil, primary coil, coupling adjuster, control switches, condenser, primary reactance coil, transformer, and silencing cabinet in which the rotary gap and motor are placed.

As far as expense is concerned, the set has been robbed of all ornament, but everything necessary to make the set convenient for operating has been provided. A set of this type is now operating at Sea Gate (near New York City).

Figures 10 and 11 illustrate the power end of a set which is built especially to meet the initial power problem. It covers the case of no local source of current supply and is therefore a general type of set. There is a 10 H. P., 4 cylinder, marine Sterling gasolene engine, with high tension ignition (shown in Figure 10), which is run at 2,000 revolutions per minute with a fly-ball governor acting on the carburetor butterfly valve to maintain constant speed. The large vertical tank in the corner is a water tank for cooling, from which the water is pumped thru the engine. The horizontal tank on the wall is a 27 gallon (102 liters) gasolene tank. The small horizontal cylinders above the engines are mufflers. The engine drives a 2 K. W., 500 cycle generator (with characteristics like those of the generator of the ship equipment) and a 32 volt, shunt wound exciter, thru a 2-to-1 gear at a speed of 2,000 R. P. M. The exciter is a 24-volt series motor for starting duty being fed by a 24 volt, 160 ampere hour, starting and lighting battery, and after starting becomes an exciter. The method of control, Figure 11, of this

Digitized by Google

outfit is interesting. The handle and wire just to the left of the center of the board are pulled down, advancing the spark for starting. The handle is attached to a guard, which upon pulling the handle down, *and only then,* discloses a push button for

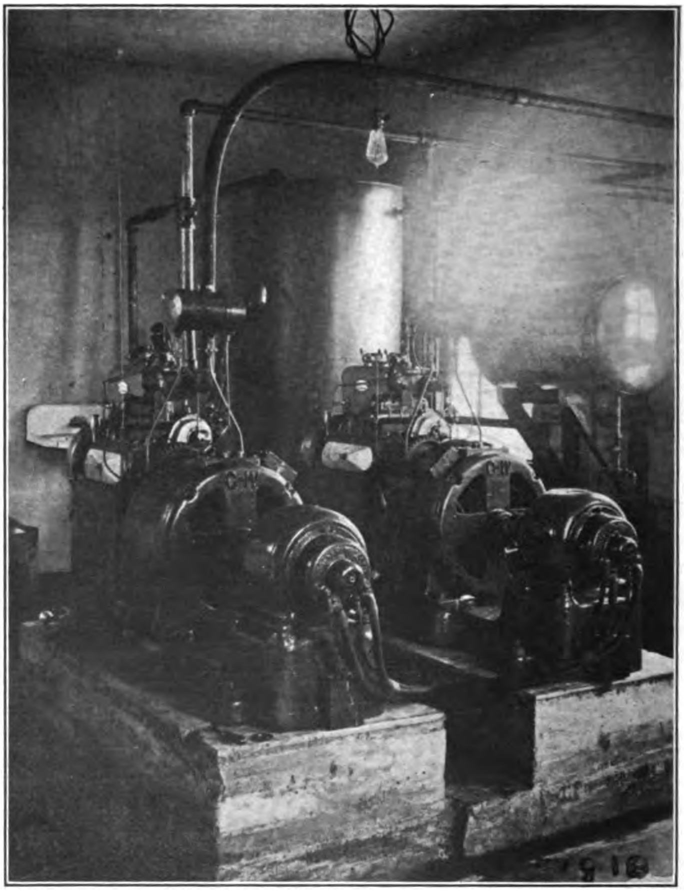


FIGURE 10—Duplicate Gasoline Engine, Alternator, and Exciter at Siasconset

starting up the outfit. The push button closes the starting clapper switch immediately to the right of the spark control. The series starter draws about 200 amperes from the battery for about a second and then falls off to zero in about eight seconds, at which time the engine has reached full speed and the series motor has become a series generator giving about 30 volts.

Digitized by Google

This is enough voltage to actuate a relay immediately above the starting clapper switch. This in turn closes the clapper switch, which causes a shift in the connections of the exciter to the shunt arrangement and throws in the generator field and all auxiliary apparatus such as gap blowers. The closing of this shift switch automatically trips the starting switch. At the

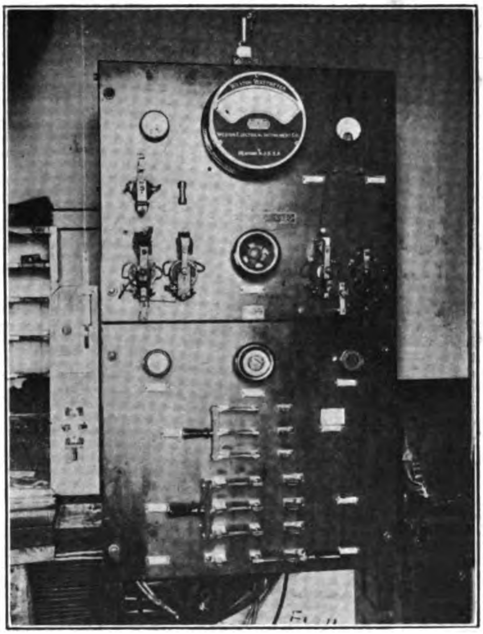


FIGURE 11—Starting, Battery, and Exciter Control Panels at Siasconset

same time, the third clapper switch in the row of four closes the battery charging circuit, which connects the battery to the exciter thru an ammeter (in the upper left hand corner) and thru the 15 ampere charging resistance located between the clapper switches. The fourth clapper switch automatically opens the charging circuit when the batteries are fully charged. A voltmeter in the upper right hand corner gives the battery voltage when wanted. The batteries are never used enough to become run down, so that, except for looking after the electrolyte, the control panel takes complete care of the batteries.

Digitized by Google

As to space limitations, it is obvious that a set of this kind is feasible only for stations having plenty of room; in fact, a special engine room is necessary.

To meet the heavy traffic and ensure continuous service, the complete generating outfit and the battery are made in duplicate and the lower half of the control panel makes possible the use of either battery in conjunction with either generating unit.

The radio part of the set has no distinctive features, but the set as a whole offers a very good example of a set constructed for heavy traffic and in such a way that no dependency is placed on outside power plants. A set of this kind is installed at Siasconset, Massachusetts.

As an example of how a "semi-high power" station is made to meet commercial conditions, there will be described a set which is now being constructed for Juneau, Alaska.

The traffic which Juneau is expected to handle is between Juneau and Ketchikan, Alaska, or Juneau and Astoria, Washington. The former is 200 miles (320 km.) south with very mountainous, rocky country between, thus offering poor transmitting conditions, and Astoria is 1,000 miles (1,600 km.) south with less mountainous country for the last 800 miles (1,300 km.). We expect regular thru traffic to Astoria in winter, but in summer it would take enormous power to accomplish the same result. In summer, Ketchikan will act as a relay station. A 10 K. W., 500 cycle, quenched gap set was decided on as being sufficient for the work. The transmission will all be done on one wave length of from 1,500 to 4,000 meters, which will be determined by trial and there will be no interference, so that quick wave length shifts are unnecessary. The station will also handle a small amount of ship traffic, so that a separate antenna suited to short waves will be used in conjunction with a 2 K. W., 500 cycle, quenched gap set.

Figure 12 is a plan of the station showing the location of apparatus. No special compactness of apparatus is required since a special building houses the equipment. The entire set itself is very little different from a smaller set, each unit simply being larger. The incoming 2,300 volt, 3 phase, 60 cycle supply comes thru oil switch (1), thru the 2,300-220 volt transformers (2) to the motor of the motor-generator exciter, which is stationed farthest from the operating room to minimize noise. The control panel (27) is in the operator's room. The 10 K. W. oscillation transformer and loading coils (8) and (7) are hinged spider coils suspended from a post. (16) and (17) are the

Digitized by Google

2 K. W. oscillation transformer and loading coil. (14) is the 10 K. W. condenser and (22) is the 2 K. W condenser. The quenched gaps (15) can be thrown by switches into either the

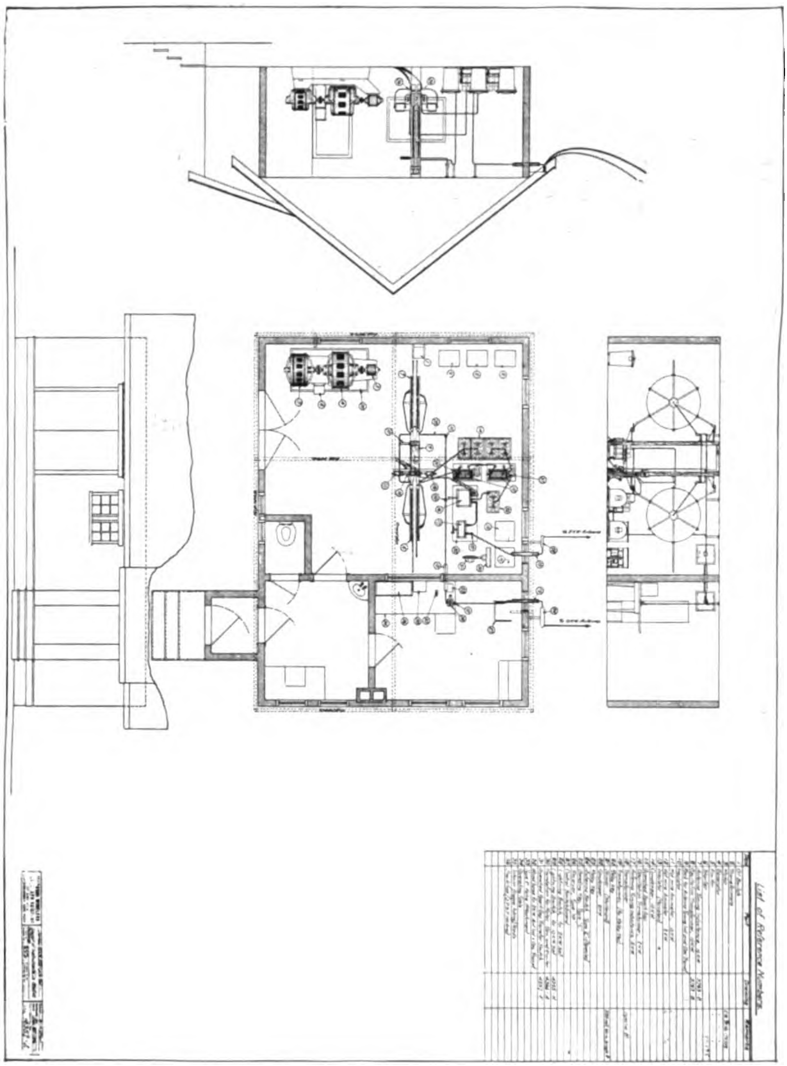


FIGURE 12—Plan of Marconi Company, 10 K. W., Quenched Spark Station at Juneau, Alaska

10 K. W. or 2 K. W. oscillation circuits which are always tuned ready for use. For 2 K. W. working an added reactance coil is inserted in the generator circuit and the 10 K. W., 500 cycle

Digitized by Google

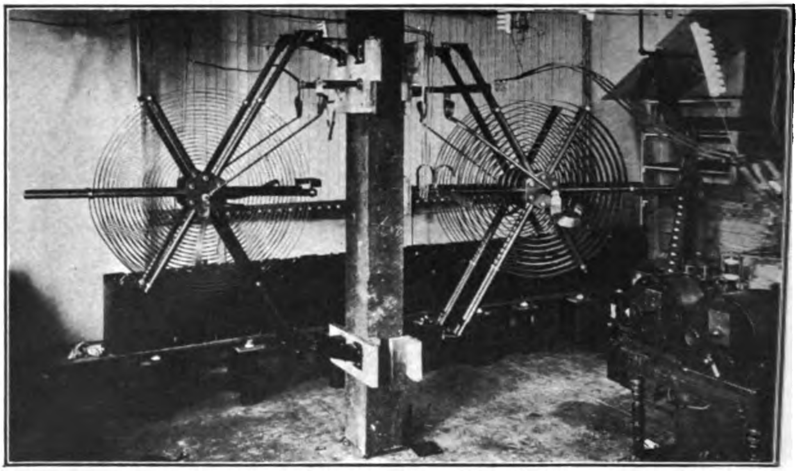


Figure 13—Radio Frequency Inductances for 10 K. W., Quenched Spark Set at Juneau, Alaska

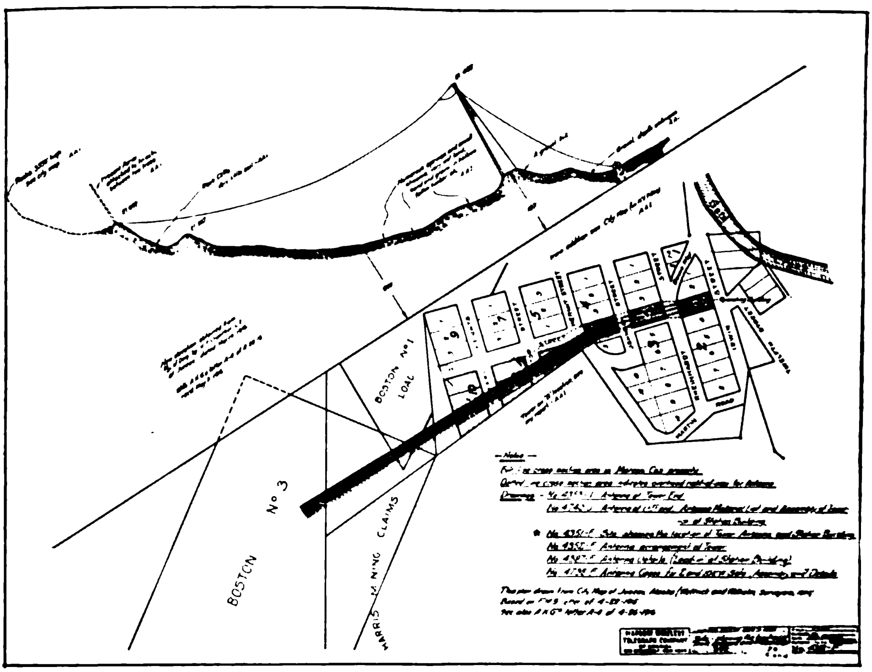


Figure 14—Antenna at Juneau, Alaska Station

Digitized by Google

transformer and machine are used for 2 K. W. working. The 10 K. W. radio frequency coils are interesting types of inexpensive construction for high power work and are shown in Figure 13. The picture shows them set up at the Aldene factory.

The 10 K. W. antenna, shown in Figure 14, is of special interest and carries out ideas based on the space factor. The line of communication is south so that a site was bought in that direction to give whatever directional aid is possible. The entire town lies on a hill side, and the site was so chosen as to give the proper direction to whatever reflection would occur. The antenna will terminate about 200 or 300 feet (60 or 100 meters) short of the bluff itself to prevent any closed loop effect.

It is hoped that in placing before the reader the chief factors controlling the construction of transmitters there have been brought out those other features which must be taken into consideration in the application of the radio art, namely, the practical commercial conditions.

SUMMARY: Six types of commercial sets are considered:

1. A 2 k.w., Quenched or Rotary Synchronous Spark, Ship Set;
2. A 0.5 k.w., Quenched or Rotary Synchronous Spark, Ship Set;
3. A 0.25 k.w., Rotary Non-Synchronous Spark, Cargo Ship Set;
4. A 3 k.w., Rotary Non-Synchronous Spark, Land Station Set;
5. A 2 k.w., Quenched Spark, Gasoline engine driven, Land Set;
6. A 10 k.w., Quenched Spark Land Set for Juneau, Alaska.

Photographs and descriptions of these are given, with special reference to nature of traffic, power source, space limitations, and expense.

Digitized by Google

DISCUSSION

George S. Davis: One of the most important features dealt with in Mr. Barth's paper is that which permits an operator, either skilled or unskilled, instantly and accurately to shift to any one of a number of predetermined wave lengths. While neither the idea nor the mechanism by which the shifting is accomplished is new or novel, the fact that it was included in the design of a "standard" ship equipment testifies not only to the thoroness of the designing engineer but to the fact that such a device has come to be a necessity in the practical operation of a radio transmitter.

Unfortunately, both the London Convention and the Act of August 13, 1912 limit the application of this very practicable idea to such an extent that it is impossible to use it to the best advantage. In effect, these laws require that all "general public correspondence" between ships, and between ship and shore, be handled on wave lengths of 300, 600, or 1,800 meters. Now, bearing in mind that practically all correspondence with ships is "general public correspondence," and also that the 300 and 1,800 meter wave lengths cannot be employed to advantage on the average ship, it follows that the 600 meter wave length is employed almost altogether, thereby causing a great deal of interference. In other words, these laws require practically all ships and all shore stations, when communicating with ships, to use one wave length—600 meters and their practical application therefore defeats the purpose for which they were enacted, i. e., to promote safety of life at sea by regulations which would minimize interference. I do not mean to infer that we should not have radio laws and regulations, but they should be framed in such a manner and should be flexible enough to permit the Government and commercial companies to take the fullest advantage of new inventions or devices such as the one under discussion to the end that interference from all sources can be overcome and new methods devised and adopted which will permit the handling of a greater volume of traffic over a given circuit at a given time. This will result in an even greater protection to passengers and ships than they now have.

It certainly is not good engineering practice, nor to the interest of the public or to the radio art itself, to enact laws which, in effect, prohibit the use of new developments, particularly in a new field, without providing a means whereby regulations can be revised so as to meet new conditions and permit

Digitized by Google

the use of newer and more highly developed apparatus which will better accomplish the purposes for which the laws were enacted. I refer particularly to the regulations of the London Convention, which are wholly unreasonable when applied to continuous wave transmitters such as the "arc." True, several ships have been equipped with arc apparatus, but from all accounts their over-all efficiency is seriously impaired on account of having to comply with these regulations.

It is quite possible in my mind that had these regulations been flexible enough to permit the use of wave lengths more suitable for continuous waves, the development of moderate-power continuous wave sets for use on board ships would have been seriously undertaken and accomplished long ago.

The advantages offered by *continuous* over *damped* wave transmitters are such that the use of the former on shipboard would, by virtue of the increased range of transmission and reduction of interference, accomplish more in the promotion of safety of life at sea than all the regulations that could be devised covering the use of damped wave transmitters. Damped wave transmitters seem to have reached their limit of usefulness and it is to be hoped that at the next International Radio Convention the regulations will be revised in such a manner as will permit operating companies to take full advantage, particularly with respect to shipboard equipment, of developments such as continuous wave transmitters, quick wave changing devices and other devices which promote accuracy and efficiency in communication.

J. B. Elenschneider: Reports from the operator on the "Baltic" state that Seagate can be read 400 miles (650 km.) from New York because of the distinctive note emitted by the non-synchronous spark set. Altho produced by 1,167 breaks per second at the rotary spark gap, the note of the received signals is more in the vicinity of a frequency of 700 per second. The range given is over water and in an easterly direction. Inland, and particularly over Long Island Sound, the range is greatly diminished.

The antenna at Seagate is suspended from a wooden mast 125 feet (37 meters) high and is 175 feet (58 meters) long. It consists of six wires spaced 3 feet (1 meter) apart and runs from northwest to southeast at an angle of about 45 degrees. The southeast or lower end is connected to the apparatus.

The fundamental wave length is 390 meters. The trans-

Digitized by Google

mitter is tuned for wave lengths of 600, 450, and 300 meters.

The antenna currents and decrements are 9 amperes and 0.095 respectively for the 600 meter wave, 8.7 amperes and 0.1 for the 450 meter wave, and 4.8 amperes and 0.11 for the 300 meter wave.

The change of wave lengths is effected by manipulating a single switch. The coupling is held constant for the three wave lengths as far as the position of the coupling coils is concerned.

The Seagate Station is one of the busiest stations and messages follow each other so rapidly that it would not pay to stop the rotary gap motor. The motor is often kept running for eight hours at a time.

The Siasconset generating plant is the first one of its kind employed in shore stations and its principal advantage is economy. Heretofore the shore stations have been equipped with stationary engines, belt driven generators, large storage batteries and motor generators, with considerable loss of energy between these different units. In the new type generating plant, as described in the paper, the losses caused thru belt slipping, friction, heat, low efficiency of storage batteries and motor generators are reduced to a minimum, and the energy generated by the engine is directly applied to the alternator whence it is led in the form of alternating current to the power transformer.

The generating plant consists of a 10 H.P., 4-cylinder, 4 cycle marine engine geared to a 2 K.W., 500 cycle generator, the latter being flexibly coupled to a 32-volt, direct current exciter. The exciter also serves as a 24-volt motor which in connection with a 24-volt, 160 ampere-hour storage battery serves as a starter for the engine. The engine is equipped with high tension magneto ingition. The cooling is effected by a rotary water pump which sends the water from a large storage tank thru the water jackets and back again to the tank.

Another pump propels the oil from a tank thru an oil-sight into the crank and gear cases. The amount of oil is regulated by means of an adjusting screw on the pump.

The fly ball governor maintains the speed of the engine under all changes of the load on the generator-exciter set within 2 per cent. above and below normal speed.

A wire runs over pulleys from the operating to the engine room, a distance of 30 feet (9 m.). The wire is connected to the high tension magneto, which, while the engine is at rest, is held in advanced position by a spring. To start the engine,

Digitized by Google

the operator pulls down the handle of the wire which exposes a push button for closing the starting circuit. This arrangement makes it impossible for the operator to start the engine with advanced spark and cause back firing and eventual damage to the engine or gears. The engines are run at a speed of 1,000 revolutions per minute which, by means of the gear at a ratio of 2-to-1, gives the generator and exciter 2,000 revolutions per minute, which is their normal speed. A 2-to-1 reduction is of advantage insofar as the load on the starter is greatly reduced and thus permits the use of a small starter motor and batteries.

At first, straight spur gears made of cast iron and rawhide were used, but it was soon found out that under the continuous impact which is caused by the variation in the generator load while the operator is transmitting, this type of gears would not answer the purpose. The teeth of these gears wore away rapidly, and, after several weeks' use, the gears failed entirely. Owing to the peculiar conditions which are brought about by the constant change in the generator load, it was necessary to substitute straight spur gears with gears of the herringbone type.

Considerable annoyance was also caused by the noise produced by open gears. It was found that open gears, running at a pitch line speed of 2,000 feet (650 m.) per minute, even if constructed of cast iron and rawhide or fiber would produce a strong shrieking sound varying in intensity as the load on the generator was thrown on and off by the operator's sending. The solution of this problem was found in the use of a tight gear case filled with soft grease.

The starting current for the engine is approximately 250 amperes at 20 volts for the first fraction of a second. This current shows a rapid linear decay to zero amperes within 6 to 8 seconds. After this time, the engine attains its full speed and the starter motor automatically becomes a generator.

The station is located on Nantucket Island and gasolene has to be transported from time to time from the mainland in small boats. In order that the station is supplied with sufficient fuel for at least two weeks' operation, a large fuel tank is installed underground and outside of the station. This tank is connected by means of a pipe system and a rotary hand pump with a small fuel tank located near the engines. The fuel consumption of these engines is approximately one pint per horsepower hour.

The original intention was to use one generating set until it developed faults and then to use the other set for emergency,

Digitized by Google

giving the latter a running test once a week. This plan had worked out well for several weeks until the first engine developed serious gear trouble. After the straight spur gears and the standard bearings on the second set had also failed, both sets were dismantled for the purpose of changing the gears to the herringbone type, running in grease, and also to increase the size of the shafts and bearings on the generator.

Digitized by Google

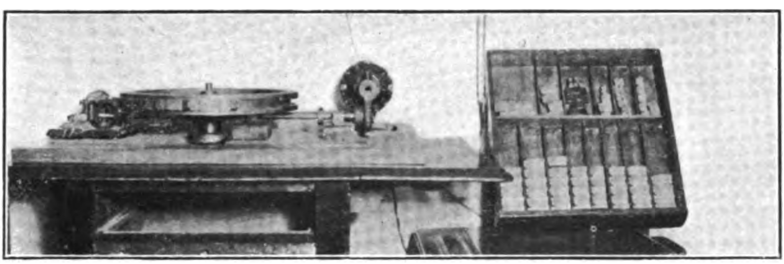
AN AUTOMATIC TRANSMITTER FOR DISTRESS SIGNALS*

By

Chester M. Agner

(Sacramento, California)

The instrument here described is principally for the purpose of giving ships that are not required by law to carry a radio apparatus a means of notifying other ships by radio telegraphy of their need for assistance, and of their position, in case of disability or disaster. This is accomplished without any assistance from a skilled operator, or one having any knowledge of radio telegraphy, or of the code used. There are at this moment many ships plying the oceans unprotected insofar as radio telegraphy may be considered a protection. They are unable to call for assistance and to advise other ships of their position in case of disaster or disability.



The apparatus mentioned consists of a brass disc, and a set of brass type blocks to be used to form a message. The disc is arranged to revolve at a speed of about 2.25 revolutions per minute, being driven by a small electric motor. The disc has a channel cut around its circumference with marginal internal flanges extending into the channel for the purpose of holding the type blocks.

The blocks are curved so as to conform to the curvature

* Received by the Editor, February 16, 1917.

Digitized by Google

of the channel of the disc. They have two longitudinal grooves on opposite sides to receive the flanges, so that the blocks cannot escape. The grooves on the blocks are of such depth that a portion of the blocks projects radially outward beyond the outer edge of the disc. On one side of each type block is stamped the information, or its abbreviation, which the block is able to transmit.

The blocks shown in the figure consist of:—

Two—S O S blocks.

One—Ship's call letters.

Abbreviation of word "longitude" (lng).

Abbreviation of word "latitude" (lt.)

Abbreviation of word "east" (E).

Abbreviation of word "west" (W).

Abbreviation of word "north" (N).

Abbreviation of word "south" (S).

Signal (D) meaning "fire."

Signal (K) meaning "disabled."

Signal (C) meaning "in life boats."

Signal (L) meaning "on rocks."

The numerals.

Space blocks marked "space."

The non-conducting portions of the blocks are made by cutting grooves crosswise on the surface about 0.125 inch (3 mm.) deep. These cuts are filled with a composition of wax (such as shoemaker's wax) and rosin. This composition is fairly hard and will adhere perfectly if in the proper proportion.

The surface of the blocks having the conducting and non-conducting portions, will be brushed by a needle when the blocks are carried by the disc as it rotates, causing the opening and closing of a battery circuit operating a relay. This acts as a key in the primary circuit of a transformer.

Electrical connection between the disc and the relay is made by the needle brush and also by making connection at the base of the perpendicular axle upon which the disc turns. Grease or oil for lubrication is not used on this axle.

To form a message, it is necessary to select the desired blocks, placing them in the channel of the disc. The flanges of the disc at a certain point are broken away, so that the blocks can be

Digitized by Google

inserted into the channel This break in the flanges is long enough to receive the longest block. The blocks can be placed on the flanges only on the right side of the entering place, because of the obstruction of a permanent stop member at the left end of the entrance. As one flange extends further out into the channel than the other, and as one groove of the block is made deeper than the other, it is impossible to insert blocks into the channel backwards.

This apparatus is designed to transmit automatically the position of a ship in case of distress, therefore the message must be arranged according to a certain form, and the spacing between words and letters, etc., is so arranged on the blocks as to comply with this form.

Form of message:—

(SOS) (SOS) (Ship's name) (longitude) 148° 17′ (W) (latitude) 24° 51′ (N) (Fire).

Words between parentheses are single blocks.

Rule:—Place a space block (marked "space") between degrees and minutes in both longitude and latitude: lng 148 17 W. lt 24 51 N.

The spacing between words, letters, or numbers, etc., is arranged on the blocks in such manner that they space automatically with the exception given in the above rule. It can therefore be seen that it is a very simple matter to set up a message. Altho this apparatus has blocks only for sending a position in latitude and longitude, other blocks may be added, such as the alphabet, so that a brief message could be formed giving the position of a ship as "so many miles from a certain point." This, of course, is not necessary.

When forming a message, the first block as it is placed in the channel should be pushed along until it is stopped by a projection in its path, at the point where the blocks were inserted into the channel. Each following block should be pushed along likewise until it is stopped by the block preceding it. When all the blocks forming the message have been placed on the flanges, the space between the last block and the part where the flanges are omitted should be filled with blank blocks having a non-conducting outer surface. These blocks are used to make the disc almost evenly balanced, so that when the ship rolls or if there is a heavy list, the motor will have a continuous even pull. If these blank blocks are not used, and the apparatus is not on a level, the motor will have a tendency to slow up and then speed as the disc revolves.

Digitized by Google

A block having a set screw is placed on the flanges at the end of the row of blocks, its purpose being to prevent the blocks from having longitudinal movement. The opposite end from the set screw block is held by means of the permanent stop member projecting into the channel.

SUMMARY: A rotating disc is arranged to carry curved blocks on its periphery. Each block permits transmitting a certain sign. Simple distress messages can thus be sent by unskilled persons.

Digitized by Google

HARMONIC METHOD OF CALIBRATING A WAVE METER*

By

E. Leon Chaffee

(Department of Physics, Harvard University, Cambridge, Massachusetts)

The following paper describes a scheme which the writer has found extremely useful as an aid in the calibration of a wave meter. The scheme makes use of the fact that a non-sinusoidal current is resolvable into a fundamental and a series of harmonics the frequencies of which are integral multiples of the frequency of the fundamental. If the frequency or the wave length of any one of the series of harmonics including the fundamental is known, then the frequency or wave length of each of the other members of the harmonic series is accurately determined.

The scheme may be useful in checking the accuracy of a wave meter already calibrated or the method may be of service in extending the calibration of a wave meter either up or down in wave lengths if a certain small range of an octave of the calibration has already been made by some other method.

In detail the method is as follows: Continuous oscillations are excited in circuit (1) of the diagram by means of an audion, Pierce mercury bulb[1], or other form of electron relay using any one of the familiar connections. A radio frequency alternator would also serve as a source of the continuous oscillations. The connections used by the writer are shown in the diagram where L_1 is a single-layer solenoid provided with a tap at its middle point; C_1 is a variable air condenser forming with L_1 the oscillatory circuit (1); R_1 is the electron relay; C_o is a stoppage condenser; B is the high-voltage battery which supplies the energy for the oscillations; and S_1 is the source of current which heats the filament of the electron relay.

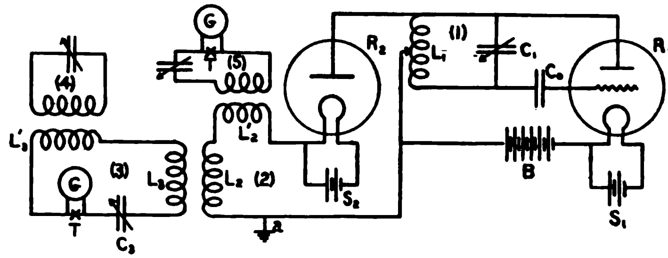
* Received by the Editor, January 15, 1917.

[1] The Pierce mercury bulb described in its original form in U. S. patent number 1,112,549, October 6, 1914, but later improved by extending the grid across the whole tube, acts as a powerful source of continuous oscillations when connected in any of the ways of connecting an audion for generating oscillations.

Digitized by Google

The oscillations in circuit (1) may, under certain conditions, show the presence of weak harmonics altho usually the oscillations are very closely sinusoidal in form. Strong harmonics may be produced by the addition of circuit (2)

Circuit (2) consists of a rectifier R_2 in series with coils L_2 and L_2' and a portion of L_1. The rectifier may be an audion with the plate and the grid connected. L_2 is a coil of 50 to 100 turns.



L_2' is a coil of a few turns and may, for the present, be omitted from consideration. Circuit (2) may be inductively connected to L_1 instead of being directly connected as shown in the diagram. The current thru L_2 consists of a series of impulses corresponding roughly to the rectified pulses obtained if all half loops in one direction of the current in circuit (1) are suppressed. Because of the non-linear resistance characteristic of the rectifier, the pulses are not sinusoidal in form. Whatever their shape, the current in L_2 can be expressed by a Fourier's series of the form

$$i = b_o + b_1 \cos \omega t + b_2 \cos 2 \omega t + b_3 \cos 3 \omega t + b_4 \cos 4 \omega t + \cdots .$$

A third circuit (3), consisting of inductances L_3 and L_3', a variable air condenser C_3, a thermocouple T shunted by a galvanometer G, is loosely coupled to circuit (2). Circuit (2) can be tuned to any of the harmonics of the current in L_2. The tuning is exceedingly sharp and is best done by means of some micrometer attachment on the condenser or by means of a long wooden handle attached to the moving element of the condenser.

The thermocouple T consists of a one mil (0.001 inch = 0.025 mm.) platinum wire rolled flat and fused at one corner to a small piece of tellurium. Its resistance is about 2 ohms. Such a thermocouple has been described by Austin.[2] G is a Leeds and Northrup 5-ohm portable galvanometer.

[2] Austin, "Bulletin of Bureau of Standards," 7, 1911, page 301.

Digitized by Google

A fourth oscillatory circuit (4) represents the wave meter under test and is shown loosely coupled to circuit (3) thru the inductance L_3'. When circuit (3) is tuned to any one of the harmonics of the current in L_2, the galvanometer shows a deflection. If now the wave meter circuit (4) be tuned so that it has the same natural period as circuit (3), the current in circuit (3), and hence the galvanometer deflection, decreases because of the absorption of energy from circuit (3). The same indicating device, namely the thermocouple and galvanometer, therefore serves to tell first, when circuit (3) is tuned to one of the harmonics, and, second, when circuit (4) is in resonance with circuit (3).

The procedure adopted in calibrating a wave meter is as follows: Condenser C_1 is adjusted so that either the fundamental or one of the harmonics falls within the previously calibrated range of the wave meter. Condenser C_3 is then varied until circuit (3) is tuned for the fundamental as shown by a maximum deflection of the galvanometer. Circuit (4) is next tuned to circuit (3). Resonance is indicated by a decrease of the galvanometer deflection to a minimum. The reading of the wave meter is observed. Circuit (3) is then tuned to the next harmonic which has double the frequency of the fundamental and circuit (4) adjusted again to reduce the deflection to a minimum. This process is repeated for several harmonics or for all that are sufficiently intense to be of use. The adjustments of the condensers for resonance in both circuits (3) and (4) are easily made with a deviation of less than 0.1 degree in 180.

It has been found usually desirable to ground point (a) to prevent resonance of coil L_2 when excited by the fluctuations in potential of the middle point of L_1 to which L_2 is connected. This precaution ensures that the excitation of L_1 comes only thru the rectifier. Even with this precaution, L_2 may oscillate if the natural period of the coil approximates the period of one of the harmonics of the impulses which pass thru the rectifier. This resonance for one harmonic is undesirable because of the resulting magnification of the corresponding amplitude in circuit (3). This great difference in amplitudes causes inconvenience because of the widely different galvanometer deflections, and may produce slight inaccuracies in the data due to the differing degrees of reaction on the oscillations of circuit (1). The oscillations of coil L_2 were successfully eliminated and properly proportioned amplitudes of the harmonics of the series were obtained by winding coil L_2 with about 100 turns of fine high resistance

Digitized by Google

wire. This added resistance is small compared with the resistance of the audion rectifier and consequently does little harm.

Unless the absorption of energy by circuit (3) is considerable, no detectable change in the frequency of the oscillations can be observed. Full scale deflections of the galvanometer were obtained with no harmful reaction on the fundamental oscillations. In case there is any doubt as to the constancy of the frequency of the oscillations of circuit (1) while circuit (3) is tuned to the series of harmonics, it is well to couple loosely to circuit (2) thru L_2' a control circuit (5) which may be tuned to the fundamental and used to detect any slight change in frequency.

A typical series of harmonics and the corresponding galvanometer deflections are given in the following table:

Harmonic	Deflection	Harmonic	Deflection
1	72.	5	3.6
2	66.	6	2.2
3	12.	7	0.8
4	11.		

The scheme described above was used by the writer in the calibration of a certain wave meter which has a range from 100 meters to 10,000 meters. A part of the scale from about 500 meters to about 1,800 meters was calibrated by the rotating-mirror method. The accuracy of this calibration was checked and the calibration extended both up and down in wave lengths to cover the entire range of the instrument.

Cruft Laboratory, Harvard College.

SUMMARY: The output of an electron relay oscillator is passed thru a non-resonant, rectifying circuit. The rectified radio frequency is rich in upper harmonics. These are used to calibrate a wave meter after a limited range thereof has been calibrated by another and absolute method. Details of the requisite procedure are given.

Digitized by Google

DISCUSSION

Julius Weinberger (communicated): This method of calibrating a wave meter also forms an extremely easy means of determining an electrical constant which has heretofore been rather a difficult one to measure—namely, the effective capacity of a coil, when used as a wave meter inductance (that is, connected in circuit with a variable condenser).

Suppose the wave meter condenser is calibrated, for capacity, say at audio frequency. Now, if we tune the wave meter (circuit 4 in the paper) to the fundamental wave length and note the condenser capacity (say C_1), and then to the second harmonic, again noting the condenser capacity (say C_2), we have:

(1) For the fundamental,

$$59.6\sqrt{L\,(C_1+C_L)}=\lambda_1$$

(2) For the second harmonic,

$$59.6\sqrt{L\,(C_2+C_L)}=\frac{\lambda_1}{2}$$

where C_L is the effective capacity of coil L.

Therefore, dividing, we get

$$\sqrt{\frac{C_1+C_L}{C_2+C_L}}=2$$

$$\frac{C_1-4C_2}{3}=C_L.$$

For example, if $C_1=2276\ \mu\mu f$ and $C_2=548\ \mu\mu f$,
Then

$$C_L=\frac{2276-2182}{3}=32\,\mu\mu f.$$

The beauty of this method is that it is extremely rapid, and that it gives the actual value of the coil capacity under operating conditions. It is certainly much shorter than any other method I know of; and is independent of any other standard except the capacity of the variable condenser. The latter can be determined with great accuracy at audio frequency; and, if the inductance of the coil is measured at audio frequency, the combination of these audio frequency calibrations with the coil capacity measured at radio frequency as above, will give an unimpeachable standard wave meter calibration.

I have found that the method is applicable to any of the high power bulb oscillators, such as the large pliotrons, without the use of the rectifying scheme of the paper. These bulbs

Digitized by Google

usually give oscillations with a strong second harmonic, and running one of these on the local 235 volt circuit, I have found it quite practicable to make calibrations of various sorts, with a "current square meter" of 80 milliamperes maximum scale deflection as indicating instrument in the wave meter circuit.

Digitized by Google

THE COUPLED CIRCUIT BY THE METHOD OF GENERALIZED ANGULAR VELOCITIES*

By

V. Bush

(Assistant-Professor of Electrical Engineering, Tufts College, Massachusetts)

Abstract of Paper

In an oscillating-current circuit there is no impressed electromotive force and the sinusoids which are involved are damped.

In the alternating-current circuit, a certain function, called the impedance, may be used for the purpose of generalizing Ohm's law to apply to such circuits.

In order further to generalize Ohm's law so that it may be applied to oscillating-current circuits, an initial voltage must be used instead of an impressed voltage. The function which may be used to change this voltage amplitude into a current amplitude may be called the "*threshold impedance.*"

The alternating-current involves an angular velocity. In the oscillating-current circuit this angular velocity may be generalized to include the decrement of the circuit, and it then becomes a complex quantity. From this complex generalized angular velocity may be formed by analogy a generalized impedance. This generalized impedance is always zero for free oscillations. This law enables us to determine the generalized angular velocities, and hence the frequencies and decrements, present in the free oscillation.

The threshold impedance is derived by a single differentiation from the generalized impedance. The use of the threshold impedance furnishes a second law to be used in the determination of the amplitudes of oscillation.

These two laws completely solve the oscillating-current circuit. They are of importance only when there are several generalized angular velocities simultaneously present.

The inductively coupled circuit furnishes an example of the

*Received by the Editor November 29, 1916.

Digitized by Google

utility of the method. In order to render this solution of greater practical value, a short approximate method is given in an appendix, for solving a fourth degree algebraic equation which appears.

A list of symbols will be found at the end of the paper.

Introductory

An oscillating-current circuit is one which oscillates in the absence of impressed electromotive force. The quantities involved are thus damped sinusoids. When there is only a single frequency of oscillation, and a single decrement to correspond, such a circuit may be readily solved by the use of differential equations. When, however, there are several frequencies and decrements simultaneously present, such a solution soon becomes cumbersome, particularly as regards the determination of the constants of integration in accordance with initial conditions.

Similar difficulties were experienced in the solution of alternating-current networks. The simple series circuit was readily solved by differential equations; but complicated networks presented difficulties.

A practical method was obtained for the alternating-current case by the introduction of the concept of impedance. This impedance was simply the function of the constants of the circuit which divided into the amplitude of voltage would give the amplitude of current. The solution of a network, then, required simply a knowledge of the rules for forming the impedance of the network from the several impedances of the branches.

If we attempt to generalize this law in a similar manner so that we may apply it to the oscillating-current circuit, we are confronted with the fact that here we have no impressed electromotive force. We must then use some other voltage; and for this purpose the initial voltage present in the circuit offers itself. This initial voltage may be due to an initial charge present in a condenser; or it may be due to an initial current thru a resistance.

We seek, then, a function of the constants of an oscillating network such that it may be divided into an initial voltage to give an initial amplitude of current oscillation.

Angular Velocities

In forming the impedance of an alternating-current circuit we encounter the "*angular velocity*" of the circuit. This is the

Digitized by Google

time rate of change of the argument in the impressed voltage expression:

$$e = E \cos(\omega t) \qquad \text{volts.}$$

It receives the name "angular velocity" because of the usual representation of such a quantity by means of a revolving plane vector.

If we make use also of the symbolic operation j, such a vector may be represented by the expression:

$$e = E \varepsilon^{j\omega t} \qquad \text{volts.}$$

In an oscillating-current circuit we have present also logarithmic decrements.

In the expression:

$$A \varepsilon^{nt} \qquad \angle$$

where $$n = -a + j\omega \qquad \text{hyp./sec.} \angle$$

we have both the usual angular velocity and the decrement present, for the expression may be rewritten in the form:

$$A \varepsilon^{-at} \varepsilon^{j\omega t} \qquad \angle$$

when it is seen to consist of the alternating-current term, multiplied by a damping factor.

It will be convenient to call the complex quantity n, which includes both the angular velocity and the decrement, the "generalized angular velocity" of the circuit.

Using this generalized angular velocity, we may form generalized impedances, admittances, etc., by analogy with the alternating-current case.

First Law of Oscillating-Current Circuits

If an alternating current of angular velocity ω passes thru a branch of impedance Z, the voltage across the branch is given by the product of the current and impedance.

It may readily be shown that this is also true if the current is oscillatory with a generalized angular velocity n[1].

Hence it follows, since the impressed voltage in an oscillating-current circuit is zero, that *the generalized impedance of the entire circuit must be zero.*

This fact, which appears in Rayleigh's Theory of Sound. in Heaviside's "Electrical Papers," and in Helmholtz's works, may be taken as the first law of oscillating-current circuits.

The application of the law enables us to determine the un-

[1] "The Impedances, Angular Velocities, and Frequencies of Oscillating-Current Circuits"—A. E. Kennelly, "Proc. I. R. E.," 1915.

Digitized by Google

known generalized angular velocities of any given oscillating circuit, for the equation obtained on equating the generalized impedance to zero, may be solved for n. There may, of course, be several values of n, the generalized angular velocity, which appear as roots.

Upon separating these values of n into their real and imaginary portions, the decrements and angular velocities may be respectively found. In this way we may determine the damping factors and frequencies present in the free oscillation of any network.

The application of this law to practical circuits has been investigated by Eccles, Campbell and Kennelly.[2]

Second Law of Oscillating-Current Circuits

When the circuit oscillates at a single frequency, the amplitude of oscillation may be found by inspection. When several frequencies are simultaneously present, there is needed a law which will determine the amplitude of the various terms of the current expression.

If the equation from the first law:

$$z=0 \qquad \text{ohms } \angle$$

yields as roots

$$n_1, n_2, \quad \cdot \cdot \cdot \qquad \text{hyp./sec. } \angle$$

these are the generalized angular velocities of free oscillation; and it follows that the current in the circuit will be of the form:

$$i=A_1 \varepsilon^{n_1 t}+A_2 \varepsilon^{n_2 t}+ \quad \cdot \cdot \cdot \cdot \qquad \text{amperes.}$$

It is our problem to determine the A's. If E is the initial voltage of the circuit, we seek a function which will divide into E to give A.

Such a function will be found in the expression:

$$n\frac{dz}{dn} \qquad \text{ohms } \angle$$

and this expression may appropriately be called the "*threshold impedance*" of the circuit. This fact is here given without proof; as a formal proof is necessarily too long for a paper of this character.

[2] Eccles, "Electrician," 1915; "Phys. Soc. Proc.," **24**, 1912.
Campbell, "Proc. A. I. E. E.," 1911.
Kennelly, "Proc. I. R. E.," 1915.

Digitized by Google

Heaviside[3] gives without proof the following formula for the current in a network when a voltage E is suddenly applied:

$$i = \frac{E}{z(0)} + \sum_{r=1}^{m} \frac{E}{n_r \left(\frac{dz}{dn}\right)_{n_r}}$$

$$= \frac{E}{z(0)} + \frac{E}{n_1 \left(\frac{dz}{dn}\right)_{n=n_1}} \varepsilon^{n_1 t} + \frac{E}{n_2 \left(\frac{dz}{dn}\right)_{n=n_2}} \varepsilon^{n_2 t} + \cdots$$

$$+ \frac{E}{n_m \left(\frac{dz}{dn}\right)_{n=n_m}} \varepsilon^{n_m t}$$

where $n_1, n_2 \cdots n_m$ are the roots of $z(n) = 0$.

z is the generalized impedance of the circuit, a function of n. $z(0)$ is the value of the generalized impedance obtained on inserting $n = 0$.

$\left(\frac{dz}{dn}\right)_{n_r}$ is the value of $\frac{dz}{dn}$ obtained on inserting n_r for n.

Wagner[4] proves this formula by the use of the function theory. A summary of Wagner's proof is given in Appendix B of this paper.

In circuits in which the charged element is a condenser, $z(0)$ is ∞; so that the first term disappears. The second term may also be considered the current on discharge for such a case, since the charge and discharge currents are equal and opposite. If the charged element is not a condenser, the first term may not disappear, and the full formula should be used.

Heaviside's formula applies to any system, physical or electrical, of any number of degrees of freedom, in which the relation between the magnitudes involved may be expressed by linear differential or algebraic equations. The oscillating-current circuit is a special case to which the formula applies. For this case the proof as given by Wagner is valid without qualification.

The use of this formula is particularly advantageous in finding oscillating-current solutions; because of the fact that z may be formed by rules already familiar from the alternating-current circuit, without referring to the differential equations of the circuit.

---

[3] Heaviside, "Elec. Papers," Vol. 2, page 373; "Electromagnetic Theory," Vol. II.

[4] Karl Willy Wagner, "Archiv für Elektrotechnik," 1916, IV Band.

Digitized by Google

We may then state as a second law of oscillating-current circuits:

The initial amplitude of current oscillation equals the initial voltage of the circuit divided by the threshold impedance.

There will be a value of n, a value of $n\frac{dz}{dn}$, and hence a term in the current expression, corresponding to each root of the equation: $z=0$.

In forming the threshold impedance, it is necessary to form the generalized impedance z of the circuit considering the initially charged branch of the circuit as the main branch.

Solution of Circuits

If a network contains an initial store of energy in one branch, corresponding to an initial voltage E, the current of free oscillation in the circuit may be found by the following steps:

1. Form the generalized impedance z of the circuit, considering the initially charged branch as the main branch.
2. Equate to zero, and solve for n. Call the roots of the equation n_1, n_2, ...
3. Form the threshold impedance $n\frac{dz}{dn}$
4. Write the current expression in the form;

$$i=\left(\frac{E}{n\frac{dz}{dn}}\varepsilon^{nt}\right)_{n=n_1}+\left(\frac{E}{n\frac{dz}{dn}}\varepsilon^{nt}\right)_{n=n_2}+\cdots \quad \text{amperes}$$

or:

$$i=\sum\frac{E}{n\frac{dz}{dn}}\varepsilon^{nt} \quad \text{amperes.}$$

In this expression the generalized angular velocities, and the amplitudes are in general complex quantities.

Upon reducing by the use of the identity:

$$\varepsilon^{j\omega t}=\cos\omega t+j\sin\omega t$$

the imaginary portions of the expression will cancel out, leaving a real expression for i.

If there are several stores of energy initially present, they may be considered separately and the results added.

The current or voltage in a distant portion of the network may be found by combining the generalized impedances of the elements of the circuit, in the manner of simple resistances.

A case of suddenly applied electromotive force may be considered as the inverse of discharge from the final state attained.

Illustration

As a simple example to show the method, consider a condenser of capacitance C, initially charged to voltage E, and discharging thru resistance R (Figure 1)

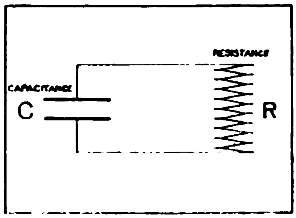


Figure 1

Here the generalized impedance is:

$$z = R + \frac{1}{Cn} \qquad \text{ohms.}$$

Equating to zero we obtain:

$$n = -\frac{1}{RC} \qquad \text{hyp./sec.}$$

The threshold impedance is:

$$n\frac{dz}{dn} = -\frac{1}{Cn} \qquad \text{ohms.}$$

Hence the current in the circuit is:

$$i = \frac{E}{n\frac{dz}{dn}}\varepsilon^{nt} = \left(\frac{E}{-\frac{1}{Cn}}\varepsilon^{nt}\right)_{n=-\frac{1}{RC}} = \frac{E}{R}\varepsilon^{-\frac{t}{RC}} \qquad \text{amperes.}$$

This result may be checked by inspection.

The Coupled Circuit

The method is very useful for the solution of the circuits which occur in radio work.

It will be illustrated on the simple inductively coupled circuit.

In the circuit of Figure 2, R_1, L_1, C_1, are the primary, and $R_2 L_2$, C_2 the secondary constants. M is the coefficient of mutual induction. The primary condenser is considered as discharging from an initial voltage E.

Digitized by Google

Form the generalized impedance of the circuit, considering the primary as the main branch.

For an alternating-current of angular velocity ω, the impedance of such a circuit is well known to be:

$$z_1 - \frac{(M\omega)^2}{z_2} \qquad \text{ohms}$$

where z_1 is the impedance of the primary and z_2 of the secondary alone.[5]

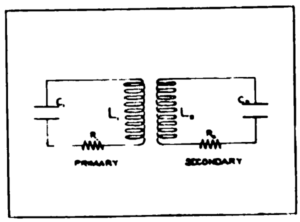


FIGURE 2

Hence, by analogy, we have as our generalized impedance:

$$z = R_1 + L_1 n + \frac{1}{C_1 n} - \frac{M^2 n^2}{R_2 + L_2 n + \frac{1}{C_2 n}} \qquad \text{ohms.} \angle$$

Equate to zero, and clear of fractions and we obtain:

$$C_1 C_2 (L_1 L_2 - M^2)\, n^4 + C_1 C_2 (R_1 L_2 + R_2 L_1)\, n^3 + (C_1 L_1 + C_2 L_2 + C_1 C_2 R_1 R_2)\, n^2 + (C_1 R_1 + C_2 R_2)\, n + 1 = 0.$$

Solve this fourth degree equation for n; and we obtain as roots the four values of the free generalized angular velocity:

$$n_1,\ n_2,\ n_3,\ n_4 \qquad \text{hyp./sec.} \angle$$

Since these four roots are in general all complex, the solution of this equation is often laborious. It may, of course, be solved to any desired degree of accuracy by straightforward algebraic methods. If it is wished to avoid this labor, the approximate method given in appendix A may be used. This method gives results sufficiently accurate for most engineering purposes. The exact method may, however, be used if desired.

The threshold impedance may be found from z by a simple differentiation, and becomes on simplifying:

[5] "Impedance of Mutually Inductive Circuits," A. E. Kennelly, "The Electrician," London, Vol. XXXI, 1893, page 699.

$$n\frac{dz}{dn}=L_1 n-\frac{1}{C_1 n}-M^2\frac{L_2 n^3+2R_2 n^2+\frac{3n}{C_2}}{\left(R_2+L_2 n+\frac{1}{C_2 n}\right)^2} \quad \text{ohms.} \angle$$

Into this expression we may insert the four values of n found above.

The primary current is then given by the expression:

$$i_1=\sum\frac{E}{n\frac{dz}{dn}}\varepsilon^{nt} \quad \text{amperes} \angle$$

where the summation extends over the roots of n found from $z=0$.

The voltage induced in the secondary is found by multiplying i_1 by $-M\,n$, and is:

$$e_2=\sum -M_n\,n\frac{E}{n\frac{dz}{dn}}\varepsilon^{nt} \quad \text{volts.} \angle$$

The secondary current is then found by dividing this voltage by the generalized secondary impedance:

$$i_2=\sum\frac{-M\,n}{R_2+L_2 n+\frac{1}{C_2 n}}\;\frac{E}{n\frac{dz}{dn}}\varepsilon^{nt} \quad \text{amperes.} \angle$$

Numerical Example

This solution was applied to a test circuit at the Massachusetts Institute of Technology, and the results were checked by oscillograms and by comparison with the usual approximate methods of solution.

The constants of the circuit were:

$R_1=1.937$ ohms
$R_2=2.531$ ohms
$L_1=7.52\times10^{-3}$ henries
$L_2=7.63\times10^{-3}$ henries
$C_1=13.51$ microfarads
$C_2=24.62$ microfarads
$M=3.475\times10^{-3}$ henries
$E=7.2$ volts, initial

Inserting these values in the equation $z=0$, and reducing we obtain:

$$n^4+7.45\times10^2 n^3+1.930\times10^7 n^2+5.88\times10^9 n+6.635\times10^{13}=0$$

Digitized by Google

On solving this algebraic equation by the method of the appendix, there was obtained:

$$\left.\begin{matrix} -249.2 \pm j\,3827 \\ -123.3 \pm j\,2129 \end{matrix}\right\} \qquad \text{hyp./sec.} \angle$$

for the four free generalized angular velocities.

These four values of n, and the values of the constants inserted in the expression of $n\dfrac{dz}{dn}$, give four values for the threshold impedance. Dividing each of these values into the values of E gave the four amplitudes:

$$\left.\begin{matrix} -0.00396 \mp j\,0.1460 \\ 0.00396 \mp j\,0.0228 \end{matrix}\right\} \qquad \text{amperes.} \angle$$

Thus the primary current can be written:

$$\begin{aligned} i_1 = &(-0.00396 - j\,0.1460)\,\varepsilon^{(-249.2 + j\,3827)t} \\ &+(-0.00396 + j\,0.1460)\,\varepsilon^{(-249.2 - j\,3827)t} \\ &+(0.00396 - j\,0.0228)\,\varepsilon^{(-123.3 + j\,2129)t} \\ &+(0.00396 + j\,0.0228)\,\varepsilon^{(-123.3 - j\,2129)t} \quad \text{amperes} \angle \end{aligned}$$

Reducing the exponential terms to their trigonometric forms, and combining, this expression becomes:

$$\begin{aligned} i_1 = &\varepsilon^{-249.2t}(-0.00792 \cos 3827\,t + 0.292 \sin 3827\,t) \\ &+\varepsilon^{-123.3t}(0.00792 \cos 2129\,t + 0.0456 \sin 2129\,t) \text{ amperes.} \end{aligned}$$

or better:

$$\begin{aligned} i_1 = &0.292\,\varepsilon^{-249.2t} \sin(3827\,t - 0.0272) \\ &+ 0.046\,\varepsilon^{-123.3t} \sin(2129\,t + 0.1719) \qquad \text{amperes.} \end{aligned}$$

Here we have the amplitudes, phase relations, and damping factors for the two terms of the primary current.

To obtain the secondary current amplitudes, we have to multiply the primary amplitudes by the ratio

$$-\frac{M\,n}{R_2 + L_2\,n + \dfrac{1}{C_2\,n}} \qquad \text{numeric.} \angle$$

Inserting the values of the constants and of the roots for this ratio takes the four values:

$$\begin{matrix} -0.732 & \underline{\backslash 3^\circ 32.6'} \\ -0.732 & \overline{\backslash 3^\circ 32.6'} \\ 2.528 & \overline{\backslash 6^\circ 14.3'} \\ 2.528 & \underline{\backslash 6^\circ 14.3'} \end{matrix} \qquad \text{numeric.} \angle$$

Digitized by Google

Multiplying the four primary amplitudes by these respective ratios, gives the four secondary amplitudes:

$$\begin{array}{l} -0.00370+j\,0.1069 \\ -0.00370-j\,0.1069 \\ +0.00370-j\,0.0585 \\ +0.00370+j\,0.0585 \end{array} \qquad \text{amperes.} \angle$$

The secondary current expression may now be written in the same manner as was the primary current expression. It reduces to the form:

$$i_2=\varepsilon^{-249.2t}(-0.00740\,cos\,3827\,t-0.2138\,sin\,3827\,t)$$
$$+\varepsilon^{-123.3t}(+0.00740\,cos\,2129\,t+0.1170\,sin\,2129\,t) \qquad \text{amperes}$$

or:

$$i_2=-0.214\,\varepsilon^{-249.2t}\,sin\,(3827\,t+0.0346)$$
$$+\quad 0.117\,\varepsilon^{-123.3t}\,sin\,(2129\,t+0.0632) \qquad \text{amperes.}$$

SUMMARY: The generalized impedance z of an oscillating circuit may be formed from the generalized angular velocity of oscillation, n, by analogy with the alternating-current circuit.

Equating this generalized impedance to zero, and solving for n, gives the free generalized angular velocities of oscillation. The real and imaginary portions of these free generalized angular velocities are used to find respectively the damping factors and frequencies of oscillation of the circuit.

From z may be found the threshold impedance of the circuit $n\frac{dz}{dn}$. Dividing the initial voltage of the circuit by this threshold impedance gives the initial amplitudes of current oscillation.

The use of these two rules determines the complete expression for the oscillating current in any oscillating-current network.

The method applies to the simple inductively coupled circuit. A complete exact solution for the case of primary condenser discharge may be readily obtained. The method is of particular service in numerical problems.

An approximate method of solving the biquadratic obtained when coupled circuits are considered is given in an appendix to the paper.

Digitized by Google

APPENDIX A.

Approximate method for the solution of the fourth degree algebraic equation occurring in the coupled circuit problem.

This equation:

$$C_1 C_2 (L_1 L_2 - M^2)\, n^4 + C_1 C_2 (R_1 L_2 + R_2 L_1)\, n^3$$
$$+ (C_1 L_1 + C_2 L_2 + C_1 C_2 R_1 R_2)\, n^2 + (C_1 R_1 + C_2 R_2)\, n + 1 = 0$$

numeric $\angle$

may be written in the form:

$$n^4 + \propto n^3 + \beta n^2 + \gamma n + \delta = 0 \qquad \text{(hyp./sec.)}^4 \angle$$

where

$$\propto = \frac{L_1 R_2 + L_2 R_1}{L_1 L_2 - M^2}$$

$$\beta = \frac{L_1 C_1 + L_2 C_2 + R_1 R_2 C_1 C_2}{C_1 C_2 (L_1 L_2 - M^2)}$$

$$\gamma = \frac{R_1 C_1 + R_2 C_2}{C_1 C_2 (L_1 L_2 - M^2)}$$

$$\delta = \frac{1}{C_1 C_2 (L_1 L_2 - M^2)}$$

The approximate method depends upon the fact that the absolute values of the roots of this equation are not greatly different from the absolute values of the roots of the equation found for $R_1 = R_2 = 0$.

The equation for the circuit without resistance will be:

$$n^4 + \lambda n^2 + \delta = 0 \qquad \text{(hyp./sec.)}^4 \angle$$

where

$$\lambda = \frac{L_1 C_1 + L_2 C_2}{C_1 C_2 (L_1 L_2 - M^2)}.$$

This equation is readily solved; and will yield as roots a pair of imaginary values:

$$j x_1 \text{ and } j x_2 \qquad \text{hyp./sec.} \angle$$

Now if the desired roots of our complete equation are:

$$-a \pm j b$$
$$-c \pm j d \qquad \text{hyp./sec.} \angle$$

we may express these also in polar form as:

$$y_1 \, 7 \, \theta_1, y_1 < \theta_1$$

$$y_2 \angle \theta_2, y_2 < \theta_2 \qquad \text{hyp./sec.} \angle$$

Digitized by Google

and by examining the relations between the roots and coefficient of our algebraic equation, write:

$$(1)\quad a+c=\frac{\propto}{2}$$

$$(2)\quad y_1^2+y_2^2+4\,a\,c=\beta$$

$$(3)\quad 2\,a\,y_2^2+2\,c\,y_1^2=\gamma$$

$$(4)\quad y_1^2\,y_2^2=\delta=x_1^2\,x_2^2$$

From (4), since x_1 and y_1, x_2 and y_2 are nearly equal, we may write as a first approximation:

$$y_1=x_1\,(1-q)$$

$$y_2=x_2\,(1+q) \qquad \text{hyp./sec.}\ \angle$$

where q is a small quantity.

Also from (1):

$$\frac{\propto}{4}-a=c-\frac{\propto}{4}=p \qquad \text{hyp./sec.}$$

Substitute in (2) and (3)

$$x_1^2\,(1-q)^2+x_2^2\,(1+q)^2+4\left(\frac{\propto}{4}-p\right)\left(\frac{\propto}{4}+p\right)=\beta$$

$$\left(\frac{\propto}{4}-p\right)x_2^2\,(1+q)^2+\left(\frac{\propto}{4}+p\right)x_1^2\,(1-q)^2=\frac{}{2} \qquad (\text{hyp./sec.})^3$$

Expand, and neglect the square of q in comparison with unity:

$$(x_1^2+x_2^2)-2\,q\,(x_1^2-x_2^2)+\frac{\propto^2}{4}-4\,p^2-\beta=0 \qquad (\text{hyp./sec.})^2$$

$$\frac{\propto}{4}\,(x_1^2+x_2^2)+p\,(x_1^2-x_2^2)-2\,p\,q\,(x_1^2+x_2^2)-q\,\frac{\propto}{2}\,(x_1^2-x_2^2)=\frac{\gamma}{2} \qquad (\text{hyp./sec.})^3$$

Use as abbreviations:

$$x_1^2+x_2^2=s$$

$$x_1^2-x_2^2=t \qquad (\text{hyp./sec.})^2$$

and the equations become:

$$s-2\,q\,t+\frac{\propto^2}{4}-4\,p^2-\beta=0 \qquad (\text{hyp./sec.})^2$$

$$\frac{\propto s}{4}-2\,q\,p\,s+p\,t-\frac{\propto q\,t}{2}-\frac{\gamma}{2}=0 \qquad (\text{hyp./sec.})$$

These equations may be solved simultaneously for p and q, giving:

$$q=\frac{s\,t^2+\propto\gamma\,s-\gamma^2-\propto^2\,\delta-\beta\,t^2}{2\,t\,(2\,s^2+t^2+\propto\gamma-2\,s\,\beta)} \qquad \text{numeric}$$

Digitized by Google

and:

$$p = \frac{2\gamma - \propto s + \propto q t}{4t - 8qs} \qquad \text{hyp./sec.}$$

Since s and β are nearly equal, it is better to write a further abbreviation:

$$u = \beta - s = \frac{R_1 R_2}{L_1 L_2 - M^2}$$

and hence obtain:

$$q = \frac{\propto \gamma s - t^2 u - \gamma^2 - \propto^2 \delta}{2t\,(t^2 + \propto \gamma - 2su)} \qquad \text{numeric.}$$

We may now give the rule by which to obtain the free generalized angular velocities of the coupled circuit with constants $R_1 L_1 C_1 R_2 L_2 C_2 M$.

1. Solve the circuit without resistance. Call the absolute magnitude of the angular velocities obtained: x_1 and x_2.

2. Form the function:

$$q = \frac{\propto \gamma s - t^2 u - \gamma^2 - \propto^2 \delta}{2t\,(t^2 + \gamma \propto - 2su)}$$

where $\propto, \beta, \gamma, \delta$ are as given above,

$$s = x_1^2 + x_2^2$$
$$t = x_1^2 - x_2^2$$

and

$$u = \beta - s = \frac{R_1 R_2}{L_1 L_2 - M_2}$$

3. Write:

$$y_1 = x_1\,(1 - q) \qquad\qquad y_2 = x_2\,(1 + q)$$

and y_1, y_2 are the absolute values of the generalized angular velocities desired.

4. Form the function

$$p = \frac{2\gamma - \propto s + \propto q t}{4t - 8qs}$$

5. Write:

$$a = \frac{\propto}{4} + p$$

$$c = \frac{\propto}{4} - p$$

and a, c are the decrements desired, so that the generalized angular velocities are:

$$-a \pm j\sqrt{y_1^2 - a^2}$$

and

$$-c \pm j\sqrt{y_2^2 - c^2}.$$

Digitized by Google

As an illustration of the method to show the degree of approximation, a circuit with constants:

$$C_1 = 10^{-9} \text{ farads}$$

$$C_2 = 10^{-10} \text{ farads}$$

$$R_1 = 1000 \text{ ohms}$$

$$R_2 = 2000 \text{ ohms}$$

$$L_1 = 0.025 \text{ henries}$$

$$L_2 = 0.040 \text{ henries}$$

$$M = 0.020 \text{ henries}$$

where the resistances are purposely assumed large, was solved by the exact and the approximate methods, and gave results agreeing to at least five significant figures.

q, in this case, was 0.000870, so that the assumption that the square of q could be neglected was evidently justified.

APPENDIX B.

Summary of Wagner's Proof of Heaviside's Formula

Wagner's proof is general, and applies to physical as well as electrical systems. This abstract of the proof will treat electrical oscillating systems only.

The constant voltage, which is suddenly applied to the network, is 0 when $t<0$, and E when $t>0$. Such a function may be represented by the Fourier integral:

$$f(t) = \frac{E}{2\pi j}\int_{-j\infty}^{j\infty} \frac{\varepsilon^{nt}}{n}\, dn \tag{1}$$

where n is the complex variable of integration.[6]

This expression may be transformed to one with a closed path of integration as follows: About O, Figure 3, describe a circle of radius R. Examination will show that as R becomes infinite the integral vanishes along BCA for negative values of t, and along BDA for positive values of t. For negative values of t we may hence replace the open path of integration by the closed path of $AOBCA$, and for positive values of t by the path $AOBDA$.

Since the integrand is everywhere regular, except at the origin, it follows that the first of these integrals will be zero,

[6] Malcolm, "Transients in Submarine Cables," "The Electrician," May 10, 1912.

Digitized by Google

while the second will have the value $2\pi j$ times the residual of the integrand at the origin. This residual is unity. Hence the expression:

$$f(t) = \frac{E}{2\pi j}\int\limits_{AOBCA}^{t<0} \frac{\varepsilon^{nt}}{n}\,dn \qquad f(t) = \frac{E}{2\pi j}\int\limits_{AOBDA}^{t>0} \frac{\varepsilon^{nt}}{n}\,dn \qquad (2)$$

has the value 0 when $t<0$, and the value E when $t>0$; and hence faithfully represents our function.

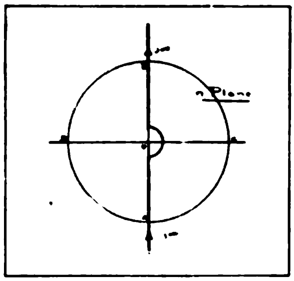


FIGURE 3

The voltage applied to a circuit, and the current in the circuit are always connected by a linear differential equation. This may be written symbolically:

$$e = F(D)\,i \quad \text{or} \quad i = \frac{e}{F(D)}$$

where D represents the differential operator $\frac{d}{dt}$.

If e follows an exponential law of variation with the time, such as:

$$\varepsilon^{kt}$$

it is well known that the current will then be of the form:

$$i = \frac{\varepsilon^{kt}}{F(D)} = \frac{\varepsilon^{kt}}{F(k)}$$

Now in our Fourier integrals above we have expressed the impressed voltage as the sum of terms of the form:

$$\frac{dn}{n}\,\varepsilon^{nt}$$

and these terms follow the exponential law of time variation.

Digitized by Google

Hence corresponding to the voltage increment there will be a current increment:

$$\frac{dn}{nZ(n)}\varepsilon^{nt} \tag{3}$$

where $Z(D)$ is the function of the differential operation from the equation of the circuit:

$$e = Z(D)\,i$$

The function Z is thus the generalized impedance of the circuit. Since the relations are linear, the effects of separate increments of the potential add simply to give the total effect.

Thus we obtain for the current in the circuit when $t>0$, the expression:

$$i = \frac{E}{2\pi j}\int_{AOBDA}\frac{\varepsilon^{nt}}{nZ(n)}\,dn \tag{4}$$

The other integral, which gives the current when $t<0$, must be zero. Hence the function $\frac{1}{Z(n)}$ can have no poles, or $Z(n)$ can have no roots, which lie in the positive half of the real plane This readily follows from physical considerations. This fact, and the limitations on $Z(n)$ when more general systems are under consideration, cannot be entered into here.

The value of the expression (4) for the current may now be determined by the evaluation of the integral.

The integrand has poles at $n=0$, and at the roots of $Z(n)=0$. Suppose these roots to be:

$$n_1, n_2, \cdots n_m.$$

Then the value of the integral is $2\pi j$ times the sum of the residuals of the integrand at 0, n_1, n_2, . . n_m. This follows from the fact that, since the integrand is everywhere regular except at these points, the path $AOBDA$, Figure 4, may be deformed into a path consisting of a small circle about each pole, Figure 5. The value of the line integral for one circuit positively about a single pole is $2\pi j$ times the residual of the function of that pole.

If N_r is the residual of the function:

$$\frac{\varepsilon^{nt}}{nZ(n)} \tag{5}$$

at the pole n_r, and N_o at the origin, then the current is given by:

Digitized by Google

$$i = E N_o + E \sum_{r=1}^{m} N_r \tag{6}$$

To determine N_r the function (5) must be developed for the region about n_r, into a Laurent series in

$$(n - n_r)$$

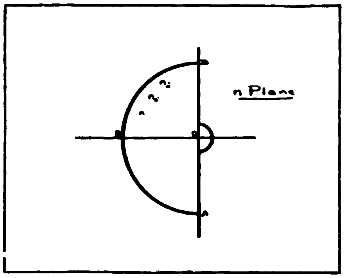


FIGURE 4

For abbreviation put $\qquad (n - n_r) = \xi$

We have the following:

$$\begin{cases} \varepsilon^{nt} = \varepsilon^{n_r t} \varepsilon^{\xi t} = \varepsilon^{n_r t} \left(1 + \xi t + \dfrac{\xi^2 t^2}{2!} + \quad \cdots \right) \\ n = n_2 + \xi \\ Z = Z(n_r) + \xi \left(\dfrac{dZ}{dn} \right)_{n_r} + \dfrac{1}{2} \xi^2 \left(\dfrac{d^2 Z}{dn^2} \right)_{n_r} + \quad \cdots \end{cases} \tag{7}$$

If the expansion of (5) is

$$\frac{\varepsilon^{nt}}{nZ} = \sum_{u=-\infty}^{u=\infty} A_u \xi^u \tag{8}$$

the coefficient A_{-1} is the residual N_r which we seek.

From (7) this may be seen to be:

$$N_r = \frac{\varepsilon^{n_r t}}{n_r \left(\dfrac{dZ}{dn} \right)_{n_r}} \tag{9}$$

To obtain the residual at the origin we use the expansion in the vicinity of the origin:

$$\frac{\varepsilon^{nt}}{nZ(n)} = \frac{\varepsilon^{nt}}{n \left(Z(0) + n \left(\dfrac{dZ}{dn} \right)_o + \quad \cdots \right)}$$

Digitized by Google

from which $$N_o = \frac{1}{Z(0)} \tag{10}$$

Using (9) and (10) in (6) we obtain finally:

$$i = \frac{E}{Z(0)} + \sum_{r=1}^{m} \frac{E}{n_r\left(\frac{dZ}{dn}\right)_{n_r}} \varepsilon^{n_r t} \tag{11}$$

which is the Heaviside formula.

In this expression the first term on the right hand side is the steady state term, and the remaining terms give the transient. In cases where the current is finally zero, the steady state term disappears.

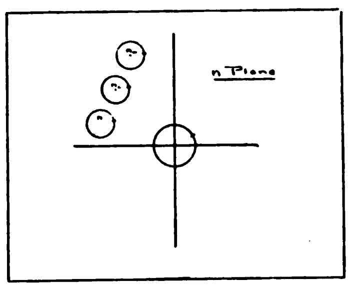


FIGURE 5

From the above derivation certain limitations as to the character of the roots of Z may be noted.

The roots must be negative in real part. Since a positive real part would mean physically, a circuit oscillating with a continuously increasing amplitude, this is of interest only in showing that Heaviside's formula is limited in application to such systems where this occurs; e. g., in the unstable arc.

The roots of Z must be distinct from each other and from zero. The case of multiple roots requires further treatment. This treatment will be found in Wagner's paper.

Singularities in Z do not appear in the treatment of the usual networks

Digitized by Google

LIST OF SYMBOLS USED

e	Instantaneous electromotive force. Volts.
i	Instantaneous current. Amperes.
E	Maximum or initial value of voltage. Volts.
I	Maximum or initial value of current. Amps.
ω	Angular velocity, $2\pi \times$ frequency. Radians per second.
n	Generalized angular velocity. Hyperbolic radians per second. $\angle$.
α	Logarithmic decrement. Hyps. per second.
j	The pure imaginary $\sqrt{-1}$.
ϵ	Base of Naperian system of logarithms. 2.718 · · · .
A	A constant amplitude. $\angle$.
z	Impedance. Ohms.
Z	Generalized impedance. Ohms. $\angle$.
R	Resistance. Ohms.
L	Inductance. Henrys.
C	Capacitance. Farads.
M	Mutual inductance. Henrys.
$\alpha, \beta, \gamma, \delta, \lambda$	Coefficients of algebraic equation.
$x_1\ x_2\ y_1\ y_2$	Absolute values of generalized angular velocities.
a, b, c, d	Rectangular components of generalized angular velocity.
$\theta_1\ \theta_2$	Polar angles of generalized angular velocity.
p, q	Correcting factors.
s, t, u	Constants.
$\angle$	Sign of a complex quantity or equation.

Digitized by Google

VOLUME 5 DECEMBER, 1917 NUMBER 6

PROCEEDINGS
of
The Institute of Radio Engineers

(INCORPORATED)

TABLE OF CONTENTS

TECHNICAL PAPERS AND DISCUSSIONS

INDEX FOR VOLUME 5, 1917

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

PUBLISHED EVERY TWO MONTHS BY
THE INSTITUTE OF RADIO ENGINEERS, INC.
ONE HUNDRED AND ELEVEN BROADWAY
NEW YORK

THE TABLE OF CONTENTS FOLLOWS ON PAGE 385

Digitized by Google

GENERAL INFORMATION

The right to reprint limited portions or abstracts of the articles, discussions, or editorial notes in the PROCEEDINGS is granted on the express condition that specific reference shall be made to the source of such material. Diagrams and photographs in the PROCEEDINGS may not be reproduced without securing permission to do so from the Institute thru the Editor.

Those desiring to present original papers before The Institute of Radio Engineers are invited to submit their manuscript to the Editor.

Manuscripts and letters bearing on the PROCEEDINGS should be sent to Alfred N. Goldsmith, Editor of Publications, The College of the City of New York, New York.

Requests for additional copies of the PROCEEDINGS and communications dealing with Institute matters in general should be addressed to the Secretary, The Institute of Radio Engineers, 111 Broadway, New York.

The PROCEEDINGS of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings in New York, Washington, Boston or Seattle.

Payment of the annual dues by a member entitles him to one copy of each number of the PROCEEDINGS issued during the period of his membership. Members may purchase, when available, copies of the PROCEEDINGS issued prior to their election at 75 cents each.

Subscriptions to the PROCEEDINGS are received from non-members at the rate of $1.00 per copy or $6.00 per year. To foreign countries the rates are $1.10 per copy or $6.60 per year. A discount of 25 per cent. is allowed to libraries and booksellers. The English distributing agency is "The Electrician Printing and Publishing Company," Fleet Street, London, E. C.

Members presenting papers before the Institute are entitled to ten copies of the paper and of the discussion. Arrangements for the purchase of reprints of separate papers can be made thru the Editor.

It is understood that the statements and opinions given in the PROCEEDINGS are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

COPYRIGHT, 1917, BY

THE INSTITUTE OF RADIO ENGINEERS, INC.

ONE HUNDRED AND ELEVEN BROADWAY

NEW YORK, N. Y.

Digitized by Google

CONTENTS

Following the Index at the end of this number are the title page, page of general information, and table of contents pages for the entire Volume 5 (1917) of the PROCEEDINGS. These last may be suitably placed at the beginning of the volume for binding.

Digitized by Google

OFFICERS AND BOARD OF DIRECTION, 1917

(Terms expire January 2, 1918; except as otherwise noted.)

PRESIDENT

MICHAEL I. PUPIN

VICE-PRESIDENT

JOHN L. HOGAN, JR.

TREASURER

MAJOR LOUIS R. KRUMM

SECRETARY

DAVID SARNOFF

EDITOR OF PUBLICATIONS

ALFRED N. GOLDSMITH

MANAGERS

(Serving until January 7, 1920)

ERNST F. W. ALEXANDERSON

JOHN STONE STONE

(Serving until January 1, 1919)

CAPTAIN EDWIN H. ARMSTRONG

GEORGE S. DAVIS

(Serving until January 2, 1918)

LOUIS W. AUSTIN

JOHN HAYS HAMMOND, JR.

LLOYD ESPENSCHIED

WARREN F. HUBLEY

ROY A. WEAGANT

ADVERTISING MANAGER

LOUIS G. PACENT

WASHINGTON SECTION

EXECUTIVE COMMITTEE

CHAIRMAN

MAJOR-GENERAL GEORGE O. SQUIER
War Department,
Washington, D. C.

SECRETARY-TREASURER

GEORGE H. CLARK
Navy Department,
Washington, D. C.

CHARLES J. PANNILL
Radio, Va.

BOSTON SECTION

CHAIRMAN

A. E. KENNELLY,
Harvard University,
Cambridge, Mass.

SECRETARY-TREASURER

MELVILLE EASTHAM,
11 Windsor Street,
Cambridge, Mass.

SEATTLE SECTION

CHAIRMAN

ROBERT H. MARRIOTT,
715 Fourth Street,
Bremerton, Wash.

SECRETARY-TREASURER

PHILIP D. NAUGLE,
71 Columbia Street,
Seattle, Wash.

Digitized by Google

SAN FRANCISCO SECTION

CHAIRMAN

W. W. Hanscom,
848 Clayton Street,
San Francisco, Cal.

SECRETARY-TREASURER

V. Ford Greaves,
526 Custom House,
San Francisco, Cal.

H. G. Aylsworth
145 New Montgomery Street,
San Francisco, Cal.

PAST-PRESIDENTS

SOCIETY OF WIRELESS TELEGRAPH ENGINEERS

John Stone Stone, 1907–8
Lee De Forest, 1909–10
Fritz Lowenstein, 1911–12

THE WIRELESS INSTITUTE

Robert H. Marriott, 1909–10–11–12

THE INSTITUTE OF RADIO ENGINEERS

Robert H. Marriott, 1912
Greenleaf W. Pickard, 1913
Louis W. Austin, 1914
John Stone Stone, 1915
Arthur E. Kennelly, 1916

STANDING COMMITTEES

1917

COMMITTEE ON STANDARDIZATION

John L. Hogan, Jr., *Chairman*	Brooklyn, N. Y.
E. F. W. Alexanderson	Schenectady, N. Y.
Edwin H. Armstrong	New York, N. Y.
Louis W. Austin	Washington, D. C.
Ferdinand Braun	Strassburg, Germany
A. A. Campbell Swinton	London, England
George H. Clark	Washington, D. C.
William Duddell	London, England
Leonard Fuller	San Francisco, Cal.
Alfred N. Goldsmith	New York, N. Y.
Guy Hill	Washington, D. C.
Lester Israel	Washington, D. C.
Frederick A. Kolster	Washington, D. C.
George H. Lewis	Brooklyn, N. Y.
Valdemar Poulsen	Copenhagen, Denmark
George W. Pierce	Cambridge, Mass.

Digitized by Google

JOHN STONE STONE	New York, N. Y.
CHARLES H. TAYLOR	New York, N. Y.
ROY A. WEAGANT	Roselle, N. J.
JONATHAN ZENNECK	Munich, Germany

COMMITTEE ON PUBLICITY

DAVID SARNOFF, *Chairman*	New York, N. Y.
JOHN L. HOGAN, JR.	Brooklyn, N. Y.
ROBERT H. MARRIOTT	Seattle, Wash.
LOUIS G. PACENT	New York, N. Y.
CHARLES J. PANNILL	Radio, Va.
ROBERT B. WOOLVERTON	San Francisco, Cal.

COMMITTEE ON PAPERS

ALFRED N. GOLDSMITH, *Chairman*	New York, N. Y.
GEORGE H. CLARK	Washington, D. C.
MELVILLE EASTHAM	Cambridge, Mass.
JOHN L. HOGAN, JR.	Brooklyn, N. Y.
ALEXANDER MEISSNER	Berlin, Germany
SIR HENRY NORMAN	London, England
WICHI TORIKATA	Tokyo, Japan

SPECIAL COMMITTEES

COMMITTEE ON INCREASE OF MEMBERSHIP

WARREN F. HUBLEY, *Chairman*	Newark, N. J.
J. W. B. FOLEY	Port Arthur, Tex.
LLOYD ESPENSCHIED	New York, N. Y.
JOHN L. HOGAN, JR.	Brooklyn, N. Y.
DAVID SARNOFF	New York, N. Y.

Digitized by Google

SOME EXPERIMENTS WITH LONG ELECTRICAL CONDUCTORS*

By

John H. Morecroft

(Associate Professor of Electrical Engineering, Columbia University, New York City)

The object of this paper is to give an elementary non-mathematical discussion of long electrical conductors, showing how the apparent inductance, capacity and resistance of such conductors depend upon the frequency, loading, etc.; also to show the distribution of current and potential along such conductors, with particular reference to the case of quarter wave length oscillations such as are used in radio antennas. The subject is treated altogether from the experimental standpoint; from the experiments described certain relations are obtained which may prove useful in calculating the oscillation period of an antenna.

By the term "long electrical conductor" is meant one on which an appreciable portion of a wave length is developed. In this paper the conductors considered particularly have electrical lengths equal to from one quarter to one twentieth of the wave length of the impressed frequency. It is to be remembered that the electrical length of a conductor depends entirely upon the frequency used in exciting it; thus a 100 mile (160 km.) 25 cycle transmission line is a short electrical conductor, while a 1,000 foot (300 m.) long antenna excited by a frequency of 100,000 cycles per second is a long electrical conductor.

Another way of distinguishing short conductors from long ones is this:—in a short conductor (loaded only at its end) the current is practically the same thruout the whole length of the line but in a long electrical conductor the value of current varies widely thruout the length of the conductor. Thus the transmission line 100 miles (160 km.) long might have a current of 100 amperes at the generator end and 98 amperes at the load end while the 1,000 foot (300 m.) antenna might have 100 amperes at the beginning and would have no current at all at the farther end.

* Received by the Editor, March 19, 1917.

Digitized by Google

Wave propagation over long conductors has been presented critically by such writers as Heaviside, Pupin, Campbell, Kennelly, Cohen, and others; study of these discussions gives one a complete knowledge of wave phenomena but there are many who have not the time for such study and who would doubtless appreciate an elementary discussion, especially of the standing wave phenomena encountered in radio work. It is hoped that the experiments outlined in the following pages may prove interesting to such readers.

An electrical conductor, such as an antenna, differs from the ordinary alternating current circuit, in that its inductance and capacity are *distributed*; the formulas which solve circuits having concentrated inductance and capacity do not, in general, hold good just because of the distributed character of the inductance and capacity. To illustrate this point let us consider two circuits as illustrated in Figure 1. In sketch *a* are shown a certain inductance L and a capacity C; if the voltage of the exciting alternator is held constant and the frequency is varied it will be found that at a certain frequency the current is a maximum and power factor is unity. Moreover there will be found only *one frequency* where these conditions hold. This frequency is given by the well known formula

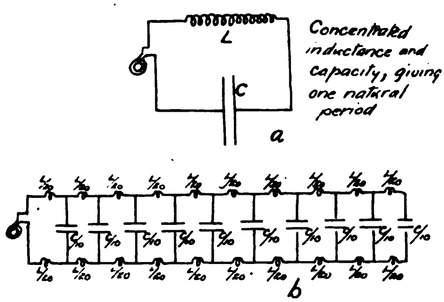
$$f = \frac{1}{2\pi} \sqrt{LC}.$$

Now in sketch *b* is shown the same amount of inductance and capacity but it is divided into small parts and distributed uniformly. If now we excite this circuit as before, with constant voltage and varying frequency, there will be found *many frequencies* at which the power factor is unity and at which the current has a maximum value and none of these frequencies satisfy the above formula for resonance. Of course there can be only one frequency which gives a real maximum of current but the other resonant frequencies give current values nearly equal to the maximum value and much larger than the values of current for frequencies slightly higher or lower than the one in question.

The first experiments were carried out to illustrate this feature of multiple resonance of the distributed L and C conductor. Instead of actually using a long line an artificial line was used in the laboratory. This line was made up of nine coils and condenser sections. The coils were wound of stranded conductor and each had an inductance of 0.0415 henry and re-

Digitized by Google

sistance of 0.702 ohm. They were air core coils and weighed about 75 lbs. (34 kg.) each. The capacity units were some specially built telephone condensers, having rather small losses (at the frequencies used) and capable of withstanding 750 volts. They were rated at 1 μf each but on measurements showed an average capacity of 0.915 μf. About four hundred of these condensers were used in some of the tests.



Distributed inductance and capacity, giving many natural periods

FIGURE 1

These coils and condensers made possible an electrical conductor of large enough current capacity that ordinary ammeters and voltmeters could be used for most of the measurements. One would not be justified in procuring such expensive capacity and inductance for carrying out the tests to be described, but the equipment had been purchased for some other experimental work and proved well suited for the work I wanted to do. Altho low frequencies were used the damping was so low that the results obtained probably compare favorably with those obtaining on an actual antenna.

This line made up of coils and condensers is styled a "lumpy line"; but it is shown in standard works that when the number of lumps is greater than six per wave length the lumpy line acts nearly enough like a uniform line. In most of my tests there were more than twenty-five lumps per wave length.

The results of the first experiment are shown in Figures 2 and 3. A voltage of 20 was maintained constant as the frequency impressed varied from 12 cycles to 152 cycles per second. It will be seen from Figure 1 that three resonant points (meaning by resonance, maximum current) were obtained and a fourth

Digitized by Google

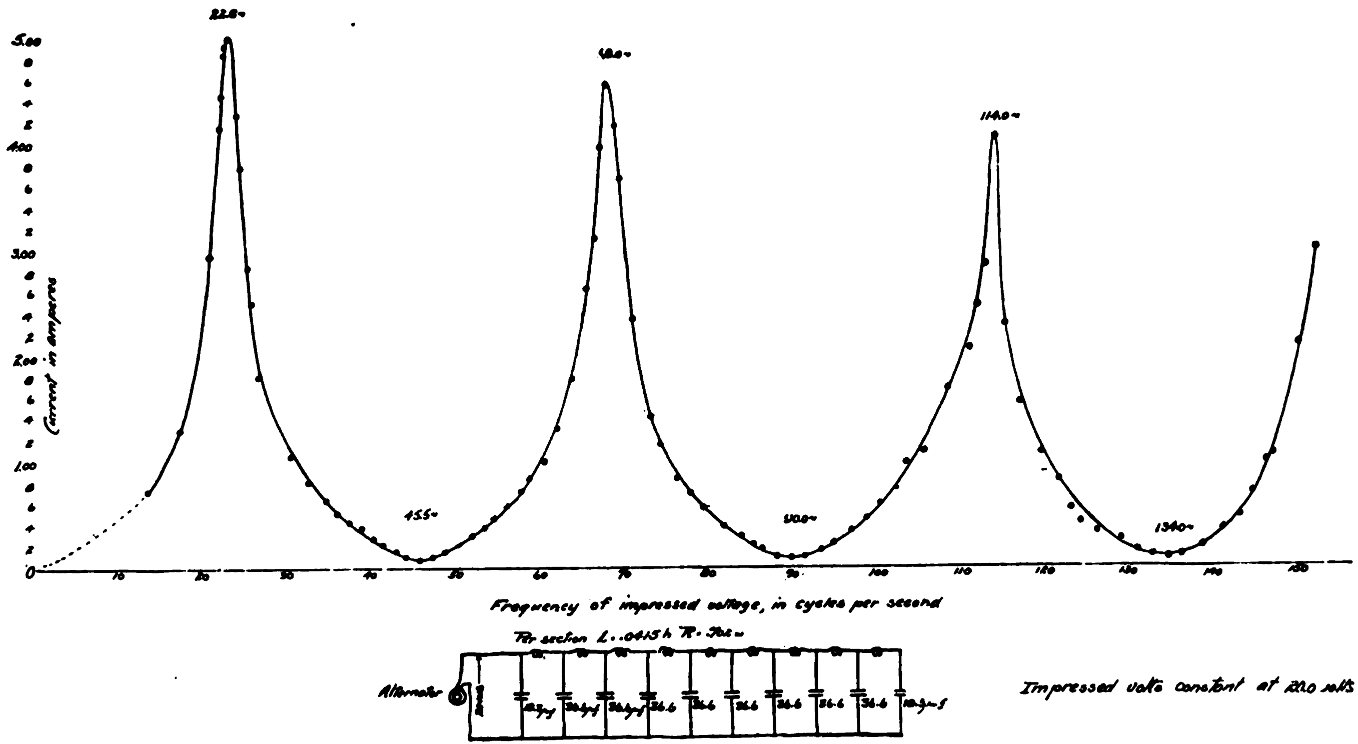


FIGURE 2

Digitized by Google

one was nearly defined. The upper frequency was limited by safe speed of the alternator. Other alternators were available which could extend the frequency range to 600 cycles; they could not be used however, as their wave forms were not pure and purity of wave form is absolutely necessary in performing tests of this character.

Besides the ammeter and voltmeter, a wattmeter was used to measure the power supply to the line. Then from the readings of the three instruments, voltmeter, ammeter, and wattmeter, it was possible to obtain the apparent resistance of the line, the reactance and the angle of phase difference between E and I. These results are shown in Figure 3.

It at once appears that such a line cannot be said to have any definite resistance or reactance unless the frequency is specified at which these constants are given. The resistance, for example, varies between 3 ohms and 350 ohms. The reactance varies all the way between 165 positive ohms (inductance) and 165 negative ohms (capacitance). And the angle between the voltage and current periodically changes from 75° lead to 75° lag.

When the resistance of a long line is small compared to the reactance the frequencies at which resonance occurs are all odd multiples of the lowest frequency. Thus 68 cycles is three times 22.8 cycles (the lowest frequency) and 114 cycles is five times the lowest frequency. But if we define resonance in the more general sense as being that frequency which makes the reactance of the line zero, then we notice that both even and odd multiples of the fundamental frequency give resonance. Thus we have as the resonant frequencies of this line 22.8, 45.5, 68.0, 90.0, 114.0. Within experimental error* these are all multiples of the fundamental frequency, 22.8 cycles per second.

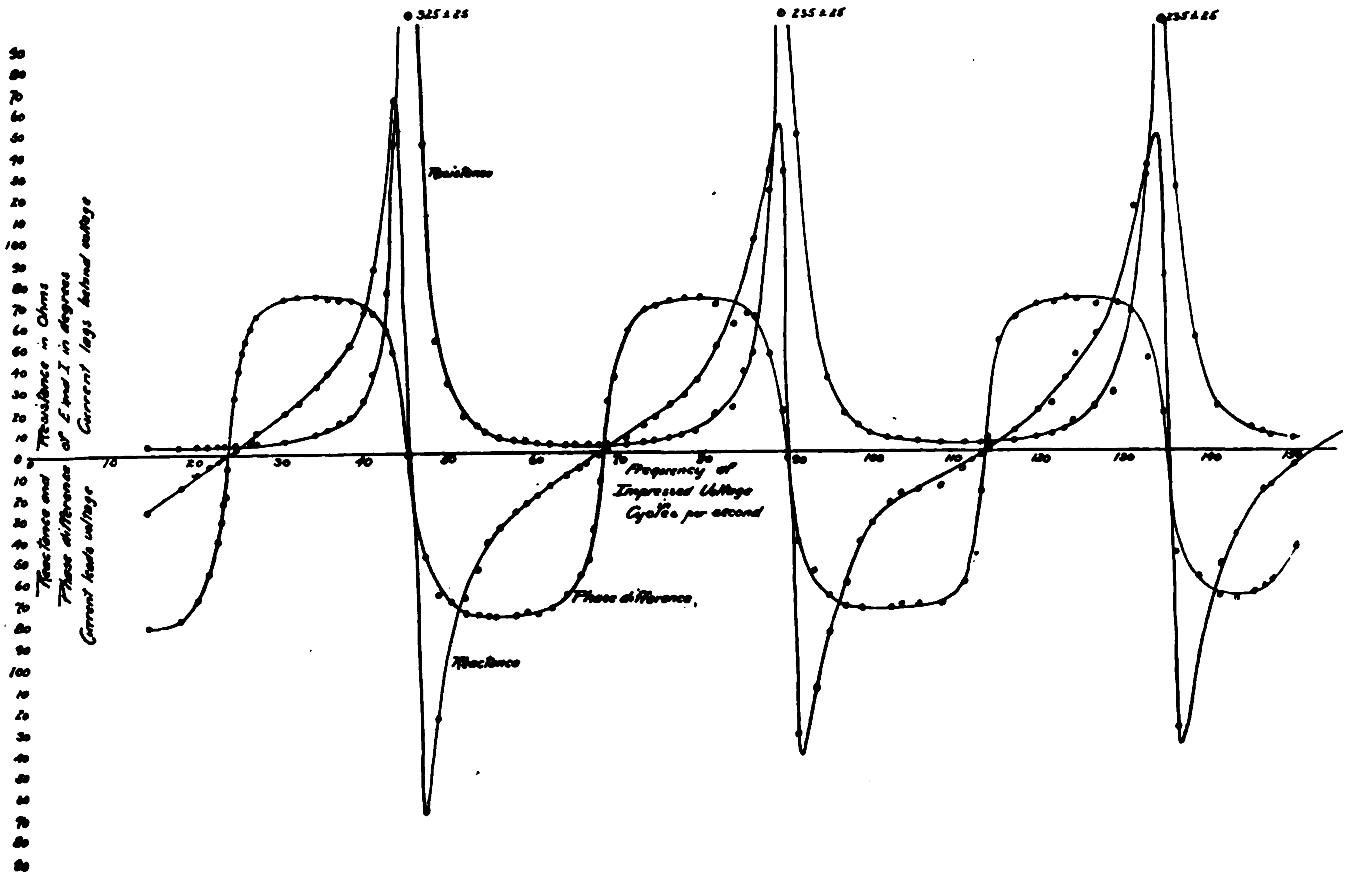
The results of above tests could have been predicted by the use of suitable formulas, such as are given in Kennelly's "Application of Hyperbolic Functions to Engineering Problems."

Thus if

r = resistance per unit length
L = inductance per unit length
g = conductance per unit length
C = capacity per unit length
f = impressed frequency
$\omega = 2\pi f$

* The accuracy of the tests outlined in this paper is probably between 0.5 and 1 per cent.

Digitized by Google



Reactance and Resistance in Ohms
Phase difference of E and I in degrees
Current leads voltage
Current lags behind voltage
Frequency of Impressed Voltage Cycles per second
Phase difference
Reactance
Resistance

FIGURE 3

$$z = r + j\,\omega L$$
$$y = g + j\,\omega C$$

Then the propagation constants of this line is

$$a = \sqrt{zy} = \sqrt{(r + j\,\omega L)\,(g + j\,\omega C)} = \alpha + j\,\beta \qquad (1)$$

and the surge impedance of the line is given by

$$z_o = \sqrt{\frac{r + j\,\omega L}{g + j\,\omega C}} \qquad (2)$$

The electrical length of the line is given by *al* where *l* is the actual length, in whatever units the other constants are defined.

Now in an open circuited line the current and impressed voltage are related by the formula

$$I_A = \frac{E_A}{z_o}\tanh al \qquad (3)$$

where I_A = entering current
E_A = impressed voltage and

tanh al is the hyperbolic tangent of the complex angle *al*.

In the line used there was no perceptible leakage in the condensers. The condensers did have some loss due to dielectric hysteresis but it was very small at the frequencies used. Moreover this loss did not vary strictly with the square of the impressed voltage and hence could not be accurately accounted for by selecting the proper value for *g*, the conductance. It was decided therefore, to neglect the condenser losses and call the conductance negligible. Then the surge impedance z_o was calculated for the various frequencies used in the test and was found to vary in magnitude but slightly. It was found to be 33.8 $\overline{\backslash 3.3^\circ}$ ohms for the low frequency and 33.6 $\overline{\backslash 0.6^\circ}$ ohms for the high frequencies. Its magnitude was taken as 33.7 ohms for all frequencies.

The current I_A should therefore vary in accordance with the variations of *tanh al* as the frequency varied. Now by inspection of charts or tables it may be seen that *tanh al* goes from maximum to minimum values as *al* goes thru the multiples of $\frac{\pi}{2}$. With the values of *al* occurring in my test *tanh al* goes from maximum values of about 11 to minimum values of about 0.08.

The calculated range of current variation is then

$$\text{maximum } I_A = \frac{20}{33.7} \times 11 = 6.4 \text{ amperes}$$

$$\text{minimum } I_A = \frac{20}{33.7} \times .08 = 0.05 \text{ ampere}$$

Digitized by Google

Actually the variation was from 5.00 amperes to 0.06 ampere, a very fair agreement when it is considered that the condenser losses were neglected. The effect of such losses is to decrease the theoretically predicted variation of current, which decrease the test actually showed.

Such an open circuited line will give various voltages at the far end as the frequency is varied, the impressed voltage remaining constant.

Theoretically, if

E_A = impressed voltage
E_B = voltage at open end
al = electrical length of line

then
$$E_B = E_A / \cosh al \tag{4}$$

where *cosh al* is the hyperbolic cosine of the complex angle *al*.

Now as *al* continually increases with increase of frequency, *cosh al* varies cyclically just as does *tanh al*. For the line tested *cosh al* varies from 0.09 to a value slightly greater than unity. The minimum values of *cosh al* occur when *al* is some odd multiple of $\frac{\pi}{2}$, that is when the line is some odd number of quarter-wave-lengths long. Formula (4) predicts that with an impressed voltage of 20 volts at 22.8 cycles the voltage at the open end should be about 220 volts. The measured value was only 157 volts or about eight times the impressed voltage. The condenser losses undoubtedly account for this discrepancy as a very slight condenser loss increases the minimum value of *cosh al* very much.

It is interesting to note here a difficulty in carrying out such tests with the facilities of the ordinary engineering laboratory. In getting the results of Figure 2, e. g., as the current varied from 5 amperes to 0.06 amperes, it was necessary to use several different range meters to read these currents. Now if a 1 ampere meter was substituted for a 5 ampere meter, everything else being the same, the input current would vary as much as 10 per cent., *due to the inductance of the meters themselves.* In getting voltages across the line for different conditions an ordinary closed circuit voltmeter could not be used at all. On some of the lines tested the voltage across the open end would drop as much as 20 per cent. as soon as the meter was connected. An electrostatic voltmeter was used for all voltage measurements; its capacity was so small compared to the line capacity that its connection did not appreciably disturb the line potential.

Digitized by Google

When an open circuited line is one quarter wave length long $\left(\text{or when its electrical length is } \frac{\pi}{2}\right)$ standing waves are set up on the conductor. These standing waves are due to successive reflections from the open end and generator end combining in the right phase to change travelling waves into stationary waves. The standing wave for quarter wave length conductor has a minimum potential at the generator end and maximum at the open end; this form of wave is exactly expressible only in hyperbolic functions of complex angles but is nearly represented by an ordinary sine or cosine wave. The current curve is also a nearly sinusoidal curve, its maximum value occurring at the generator end and zero value at the open end.

These curves of current and potential distribution are shown in all texts on radio telegraphy but, in so far as the writer knows, experimental results are rather meagre. I therefore obtained curves of voltage distribution for the nine section conductor previously described, not only for that impressed frequency which gave quarter wave length but for several others, each being such as to make the line some multiple of $\frac{\pi}{2}$ hyperbolic angles long. These frequencies are the resonant frequencies shown in Figure 3, each frequency making the reactance of the line zero. The form of voltage curve for each frequency is shown in Figures 4, 5, and 6, the notation on each curve sheet making them self explanatory. The voltage at any point on the line is obtained by scaling the distance from the zero line to the curve for the frequency in question.

In Figure 4, curve 2–2′, the form of voltage distribution curve is such as would apparently go thru zero at the center of the line. But actually the voltage at the apparent node *does not go thru zero*; actually there is no voltage node in the sense that the voltage is zero. And there never can be a node of potential on such a conductor unless energy is being supplied everywhere along the line at the same rate as it is being dissipated at that point in the line. As this is practically never the case the so-called nodes are only pseudo nodes, the minimum amount of voltage being fixed by the amount of energy which must flow past the nodal point to maintain the line in a state of oscillation. In Figure 4 this minimum voltage is about 10 volts.

The point might be raised as to how the voltage vector passes thru this nodal point. On one side of the node the voltage

Digitized by Google

has one phase and on the other side of the node the phase is just opposite, i. e., nearly 180° shift in phase occurs in passing thru the nodal point. How can this be so if the vector nowhere

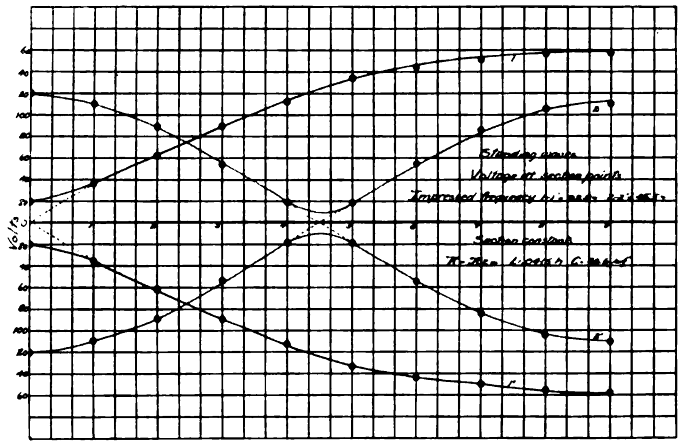


FIGURE 4

goes thru zero value? The apparent ambiguity is due to the attempt to usé a two dimensional figure where a three dimensional figure is required. The voltage vector winds around the zero line in a kind of spiral as we consider consecutive parts of

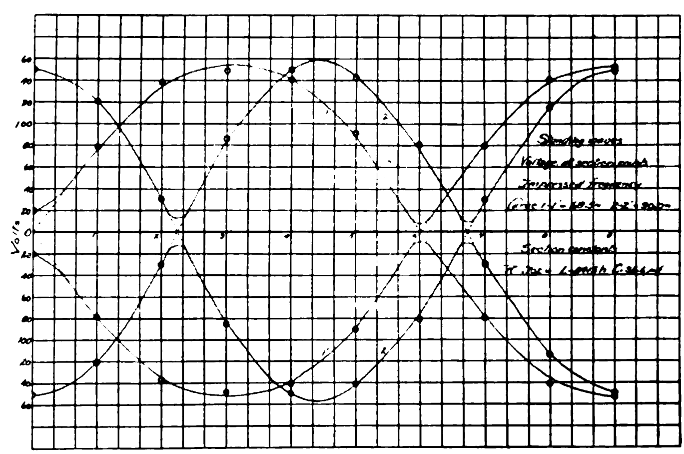


FIGURE 5

Digitized by Google

the line; this spiral comes closest to the zero line at the nodal point but does not go thru the zero line.

The foregoing material apparently has no direct application to radio telegraphy. Such is not the case, however, because there are certain problems where the distributed capacity and inductance may play a very important part in determining the node of oscillation, etc. Thus one of the long Marconi aerials,

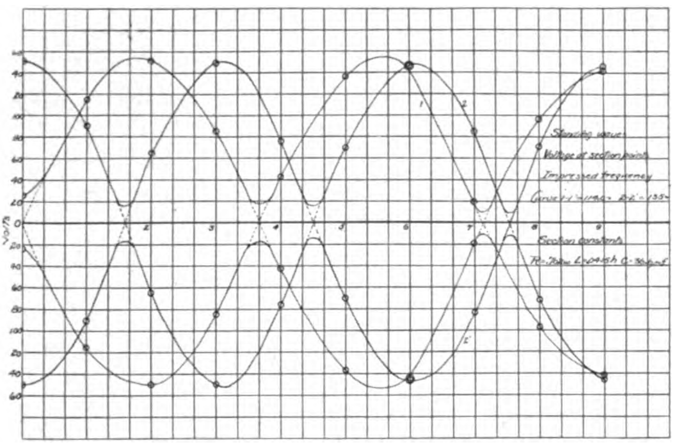


FIGURE 6

having a natural wave length of perhaps 7,500 meters, if adjusted to emit a wave length of 10,000 meters or even more, will by no means obey the ordinary equations for oscillations, connecting frequency, inductance and capacity,

Also in determining the distributed capacity of coils the ordinary formulas give entirely erroneous results. For an accurate solution of such problems it is necessary to consider the fact that the current and potential distribution largely affect the value of the constants to be determined. For attacking such problems the material already presented furnishes the right view point.

OSCILLATIONS IN AN ANTENNA

An antenna is always excited to oscillate in the quarter wave length conditions as shown in Figure 4, curve 1–1′. It could not be made to oscillate strongly at the half wave length

Digitized by Google

condition of curve 2–2′ but might oscillate very well at the three quarter wave length condition as shown by curve 1–1′ of Figure 5; also as shown by curve 1–1′ of Figure 6 which is the one and a quarter wave length oscillation.

A long uniform antenna could be made to have any of these three modes of oscillation (or others) but the normal operation for radiation efficiency requires oscillation at the quarter wave length condition. Hence further experimental data was obtained to show current and voltage distribution in a line oscillating at quarter wave length.

If a series inductance or series condenser be added in the beginning of the laboratory model the distribution of current and potential will be just the same as occur on an actual antenna to which such adjustments have been made for the purpose of lengthening or shortening the radiated wave.

Experimental data on such oscillations is given in Figures 7 thru 11. The natural frequency of the line used was 45.2 cycles. By adding 0.142 henries in series, the quarter wave length frequency dropped to 32.6 cycles per second; and by adding 0.617 henries this was further reduced to 20.5 cycles. The current and potential distribution shown in Figure 9 give the conditions as they occur in a long uniform aerial emitting a wave about 2.5 times the natural wave length. It is to be noticed that as inductance is added in the base of an antenna the potential tends to become uniform over the whole length of the antenna and the current decreases from the ground end toward zero at the open end on a nearly straight line instead of a sine curve as it does for the unloaded antenna.

With a series condenser of 165 microfarads in the base Figure 10 was obtained, and with 82.5 microfarads in the base Figure 11 was obtained. The latter corresponds to an antenna oscillating at a frequency about 30 per cent. greater than its natural frequency. The current is now a maximum not at the beginning of the line (base of the antenna) but somewhat along the line. Where the current is a maximum the voltage is a minimum. The voltage curve crosses the zero line in both Figures 10 and 11 but the voltage does not go thru zero and so the curve is shown dotted in this portion. This anomaly comes about in trying to represent the voltage curve in two dimensions, as previously noted.

The voltage impressed on the line is the same in Figures 7 thru 11. But it is seen that whereas the entering current is nearly 5 amperes for the unloaded line and the maximum voltage

Digitized by Google

is 345 volts none of the other curves show values as large as these. Thus when by loading the quarter wave length frequency has been reduced to about 40 per cent. of the natural frequency,

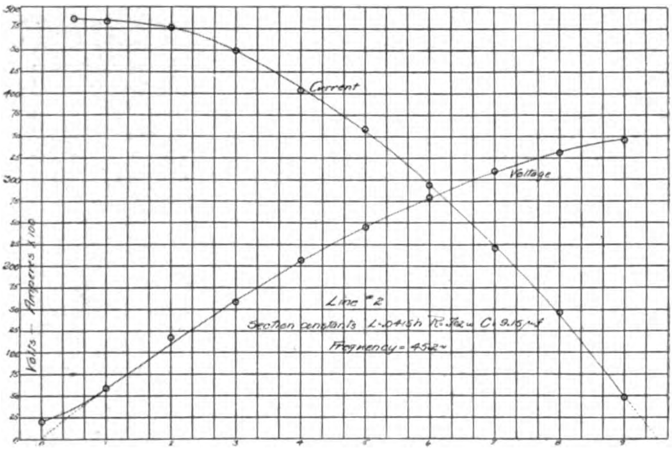


FIGURE 7

the entering current is only 1.44 amperes and maximum voltage on the antenna is 148 volts. To get the same input current as for the unloaded line would require that the impressed voltage

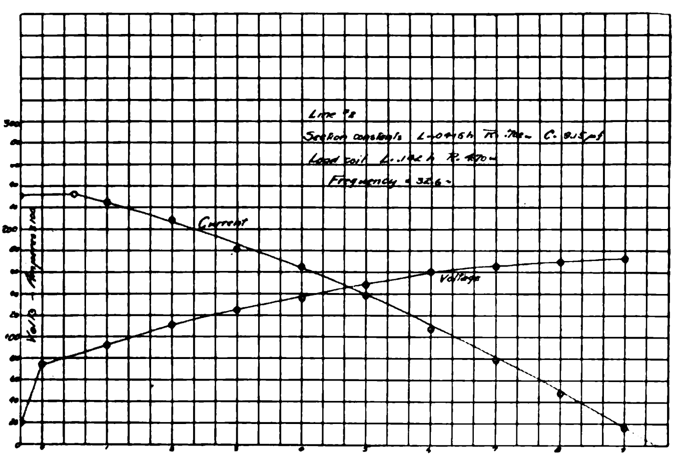


FIGURE 8

Digitized by Google

be increased more than three times. The same effect occurs when the natural frequency is increased by series condenser. Hence we see that when the wave length of an antenna is in-

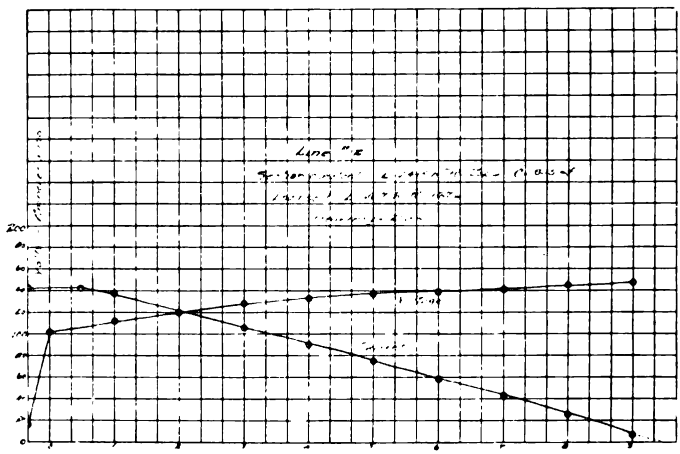


FIGURE 9

creased by loading or decreased by series condenser, it is necessary to change the adjustment of the coupling transformer if the same current is to be maintained in the antenna. The

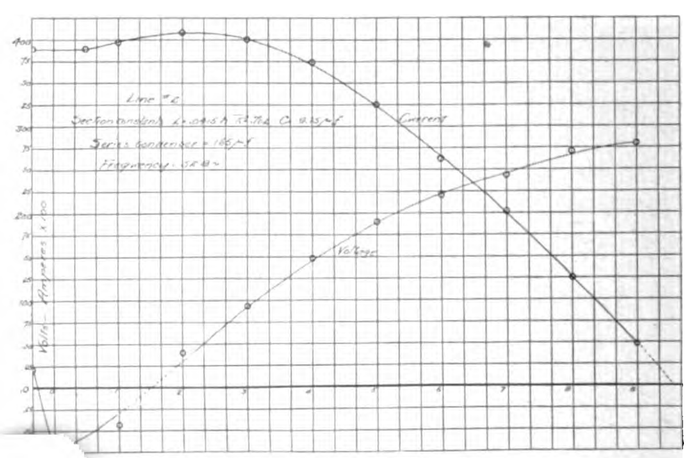


FIGURE 10

Digitized by Google

results given above apply directly, of course, only to continuous wave operation but hold good also for damped wave oscillation.

The curves of Figures 7 thru 11 show that no matter what the frequency may be at which the line is oscillating, the current and voltage distribution are nearly sine waves, just as for the unloaded line. But when the frequency is less than the natural, less than one quarter of a complete sine wave occurs and when

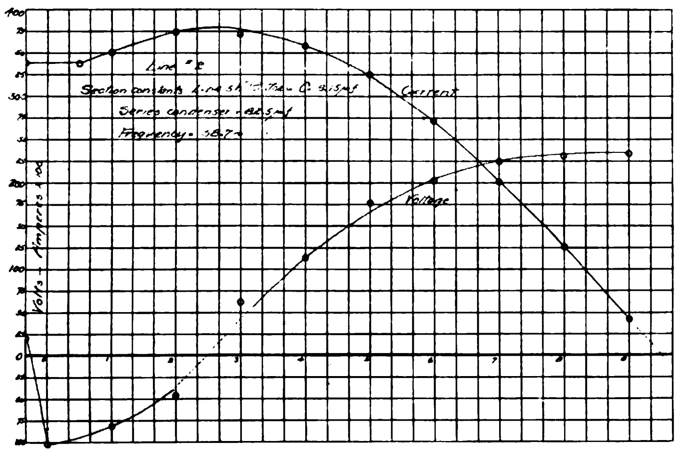


FIGURE 11

the frequency is greater, more than one quarter of a whole sine curve occurs. Thus in Figure 8, the voltage curve is 72.2 per cent. of a quarter of a sine curve when calculated from the frequency ratio, 32.6 to 45.2. This gives 64.8° of a curve and so the voltage at the beginning should be equal to voltage at the end of line multiplied by *sin* $(90° - 64.8°) = 0.426$. But the end voltage $= 172$ volts. Hence beginning voltage should be $172 \times 0.426 = 73$ volts. It measures from the curve 75 volts.

Many antennas have an irregular distribution of capacity as for example a *T* antenna which has more capacity per unit length at the top of the antenna than it has at the beginning. In Figures 12, 13, and 14 are shown the distribution of current and potential in such an antenna. The total capacity and inductance of the line is the same as was used for the previous uniform line but it is seen that the natural frequency is now only 40.1 cycles as compared to 45.2 cycles for the uniform line.

Digitized by Google

A given series condenser raised the natural frequency of the uniform line by 30 per cent. The same series condenser in the assymetrical line raised the frequency by 32 per cent. A

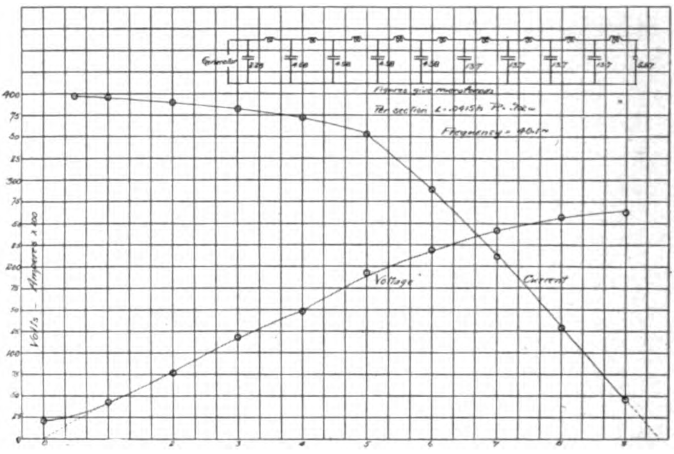


FIGURE 12

given loading inductance lowered the frequency of the uniform line to 72.3 per cent. of the natural frequency. The same inductance lowered the frequency of the assymetrical line to 77.2 per cent. of natural frequency. So that the series con-

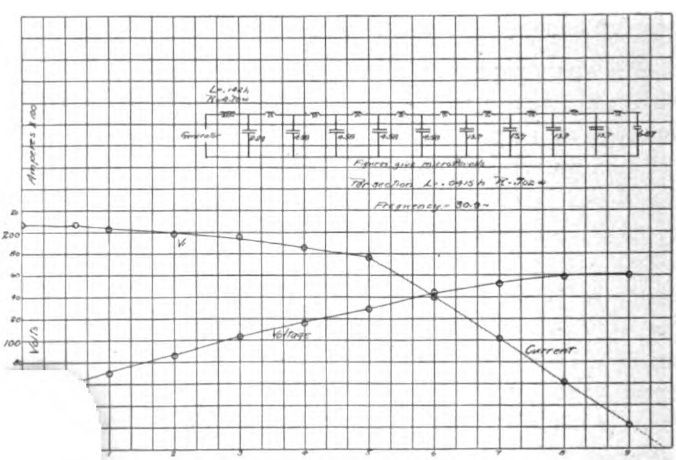


FIGURE 13

Digitized by Google

denser has more effect and the series inductance has less effect in the non-uniform line than in the uniform line.

Now as the capacity of an antenna and inductance of an antenna are continually being measured and the values so obtained used in calculations it is worth while to investigate what these quantities really are.

Three uniform conductors were first tested for quarter wave length frequency. The inductance and resistance per section in each case were 0.0415 henry and 0.702 ohm. In one case the capacity was 36.6, in the second 9.15, and in the third it was 1.83 microfarads per section.

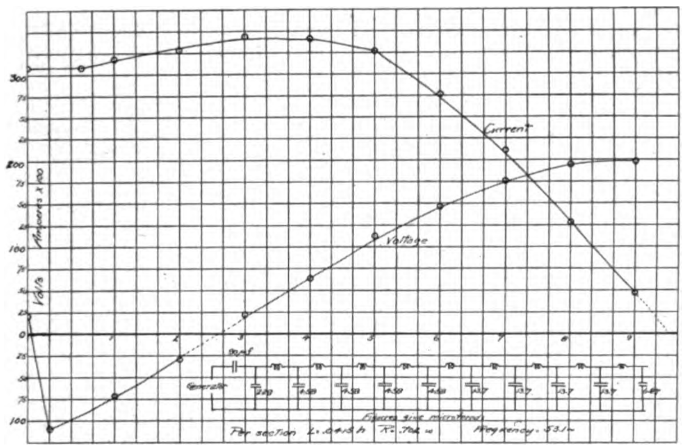


Figure 14

In the following table are shown the total inductances and capacities for each line, the frequencies calculated from these quantities, the frequency which actually gave quarter wave length vibration and the ratio of these two frequencies.

Total L		Total C	$\frac{1}{2\pi\sqrt{LC}}$	Measured Frequency	$\frac{\text{Meas. Freq.}}{\text{Cal. Freq.}}$
Line 1	0.374	329.	14.3	22.5	63.6 per cent
Line 2	0.374	82.3	28.7	45.2	63.5 per cent
Line 3	0.374	16.45	64.2	100.5	63.8 per cent

Now as in each case above the lines have no added series inductance or capacity the line was quarter wave length long and the voltage and current curves were sine waves very nearly.

Digitized by Google

But the average value of a sine wave from 0° to 90° is 63.6 per cent. of the maximum; it appears therefore, that the natural quarter wave length period of such a uniform line is a function of the form of current and potential curve of the line. As the electrostatic energy is a function of the potential curve and the electromagnetic energy is a function of the current curve and both curves have the same shape, it is logical to say that the effective self induction of such a line is equal to 63.6 per cent. of the total self induction and the effective capacity of such a line is 63.6 per cent. of the total capacity of the line.

Now even when inductance or capacity is added in series with such a line the current and potential curves are both sine curves when the frequency of impressed e. m. f. is such as to give quarter wave length vibration; it seems, therefore, that the effective capacity and self induction of such a line can be predicted for any amount of loading.

With this idea in mind a series of results was obtained to show how line number 3 acted as the series inductance loading was continually increased. For each frequency the average value of the curve of potential and current was calculated, calling the maximum value of either curve equal to unity.

Thus the quarter wave length frequency of this line unloaded was 100.5 cycles; curves of this line are shown in Figure 15. With a series loading of 0.413 henries the frequency dropped to 52.4 cycles. At this frequency the line has not an electrical length of 90°, but of $\frac{52.4}{100.5} \times 90° = 47.°$. Hence the current distribution curve will be a sine wave from 47° to 0°, and the potential curve will be a sine curve from 43° to 90°. The average value of the sine curve from 47° to 0° is 0.531 of the value of the sine of 47°. The average value of the sine curve from 43° to 90° is 0.894 of the sine of 90°.

As the total L of the line was 0.374 henries, its effective L (if previous reasoning is correct) will be $0.374 \times 0.531 = 0.199$ henries. The effective value of capacity will be $16.45 \times 0.894 = 14.73\ \mu f$. As the added inductance is 0.413 henries we would expect the line to oscillate like a circuit having $(0.413 + 0.199) = 0.612$ henries and $14.73\ \mu f$.

The natural frequency of such a system

$$= \frac{1000}{2\pi\sqrt{0.612 \times 14.73}} = 53.1 \text{ cycles.}$$

actual measured value of resonant frequency was 52.4 The other values are tabulated herewith. It will be

Digitized by Google

noticed that the agreement between predicted and measured frequencies is all that could be expected from the precision with which the test was carried out.

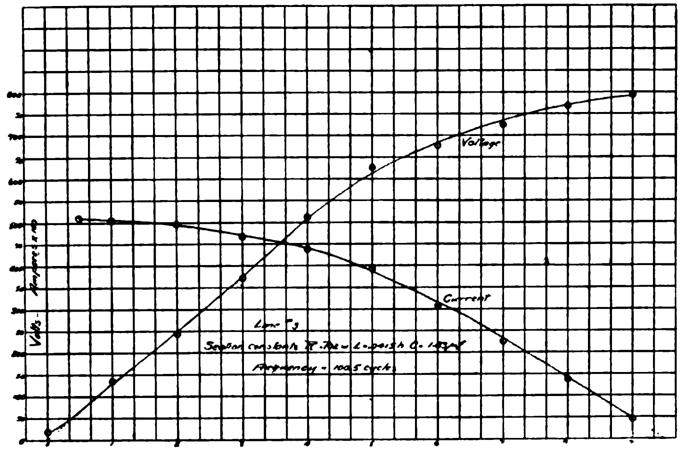


FIGURE 15

Added L	Capacity		Inductance		Calculated f	Measured f
	Av. Sine	Effect. Cap.	Av. Sine	Effect. L		
0.000	0.636	10.52	0.636	0.238	100.5	100.5
0.073	0.736	12.12	0.586	0.220	84.7	83.8
0.142	0.791	13.05	0.563	0.211	74.2	73.6
0.207	0.828	13.65	0.552	0.207	67.0	66.8
0.292	0.855	14.08	0.540	0.203	60.5	60.2
0.348	0.878	14.48	0.534	0.200	56.6	55.6
0.413	0.894	14.73	0.530	0.198	53.1	52.4
0.617	0.920	15.15	0.521	0.195	45.4	45.1
0.823	0.936	15.40	0.516	0.193	40.3	39.6
1.245	0.952	15.70	0.513	0.192	33.6	33.8

The true value of line capacity is 16.45 microfarads.

The true value of line inductance 0.374 henry.

The above results were plotted in the forms of curves and given in Figure 16. They seem important as they have an immediate application to radio calculations. In the form given above they apply directly only to a uniform antenna such as

Digitized by Google

some of the Marconi stations use, but with suitable modifications can probably be suited to fit other fairly simple forms of antennas.

It will be seen at once that the common measurement to get antenna capacity is more or less meaningless because the capacity of the antenna is a function of the frequency with which it is vibrating. The ordinary method of getting antenna capacity

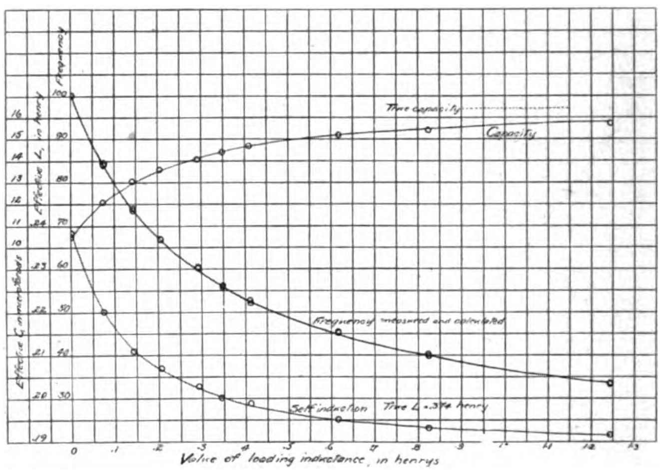


FIGURE 16

is to measure the oscillation constant when a large loading coil of known value has been inserted in the base of the antenna. From the LC thus measured, and known L, the C is calculated. Then the LC of the unloaded antenna is measured and from the C just obtained the antenna L is obtained.

Trying this method on the line used in above test would give $C = 16.40$ μf (nearly). The LC of the line unloaded gives $LC = 2.56$.

From this $L = 0.156$ henries. But the actual effective L when line is unloaded is 0.238 henries, and under no conditions does it become lower than about 0.190 henries.

Summing up the above results shows that as the series loading of an antenna is increased the effective capacity of the antenna varies from 63.6 per cent. of its true capacity up to 100 per cent. true capacity while the inductance decreases from 63.6 per cent. of its true value to 50 per cent. of its true value.

Digitized by Google

However, this analysis, which assumes change in both capacity and inductance with frequency, yields no more accurate a solution of the problem than the present method of treating both L and C constant. Thus, if we assume $C = 16.40$ μf and $L = 0.156$ henry, and calculate the natural periods of the loaded line with these values, the frequency will come out just the same as it does with the method outlined. Thus if the loading is 0.5 henry, $L = 0.656$ and $C = 16.40$. The natural frequency calculated from these values is 48.7 cycles, which agrees with the experimental result.

Resistance

As the current distribution in the conductor changes from a sine curve to a straight line with increase in loading (assuming quarter wave length mode of oscillation) the heat generated in the conductor by the $I^2 R$ loss must, of course, vary also. Hence the conductor resistance, which is obtained by dividing the total $I^2 R$ loss by the square of the value of current at the beginning of the line must vary with increased loading in some manner similar to that in which the capacity and inductance vary.

Let R = the actual conductor resistance, i. e., resistance per unit length $\times$ length,
I = current at beginning of line,
r = effective resistance of conductor.

Then for no loading it is seen that the effective value of the current is equal to the root mean square of a sine wave from 90° to 0°. This root mean square value is $0.707 \times I$, as proved in elementary alternating current theory.

Hence the actual heat loss is given by

$$\text{Loss} = (I \times 0.707)^2 R = 0.5 I^2 R$$

But this gives for effective resistance of antenna

$$I^2 r = 0.5 I^2 R \text{ or}$$

$$r = 0.5 R$$

So the effective resistance of such a uniform conductor is only one half the actual resistance.

Now as the loading is increased the current distribution tends to become a straight line. But the effective value (root mean square) of such a straight line is $\frac{1}{\sqrt{3}} \times$ maximum value. Hence for straight line current curve (very heavy loading)

$$I^2 r = \left(\frac{I}{\sqrt{3}}\right)^2 R \text{ or}$$

$$r = \frac{R}{3}.$$

Digitized by Google

Hence we should expect the effective resistance of the line to vary from 50 per cent. of its actual resistance to 33 per cent. of its actual value as loading was increased.

Readings were taken to see whether such a change actually did occur in the line used in previous tests. After adjusting the line for quarter wave length oscillation with various values of loading the power input was read by wattmeter. Then another reading of wattmeter was taken with current the same but the potential coil of the wattmeter was connected to read the power used in meters, connections, loading coils, etc. The difference of these two readings gave the power lost in heating the line.

This loss divided by the square of the current supplied to the line gave the effective resistance of the line. The total actual resistance of the line was 6.60 ohms; the effective resistance with no added inductance should be 3.30 ohms. Actually it came out 3.56 ohms. Other values of resistance for different values of loading were obtained but the results were erratic and apparently unreliable. It involved the determination of a small difference between two comparatively large quantities and moreover the condenser losses (which were neglected) apparently affected the results considerably.

Of course the results I have obtained experimentally could have been at once predicted from the laws of wave propagation.

Thus using same symbols as before

$$a=\sqrt{(r+j\,\omega L)\,(g+j\,\omega C)}=a+j\,\beta \text{ where}$$

β is the so called wave length constant of the line.
If r and g are small compared to ωL and ωC (this condition was fulfilled in my experiments) then we may write approximately

$$\beta=\omega\sqrt{LC},$$

or if we are considering a certain length of the line l

$$\beta\,l=\omega l\,\sqrt{LC}=\omega\,\sqrt{(l\,L)\,(l\,C)}=\omega\,\sqrt{L'\,C'},$$

where L' and C' are the actual total self induction and capacity of the line.

Now λ, the wave length developed on a line, is given by

$$\lambda=\frac{2\,\pi}{\beta},$$

and if we choose such a length of line that quarter wave length is developed we have

$$\text{if } l=\frac{\lambda}{4} \qquad \beta\,l=\frac{\pi}{2}.$$

Digitized by Google

Then
$$\beta l = \omega \sqrt{L' C'} = \frac{\pi}{2}, \text{ or, as } \omega = 2 \pi f,$$

$$f = \frac{1}{4 \sqrt{L' C'}},$$

so that
$$f^2 = \frac{1}{16 L' C'}.$$

As the ordinary equation for resonance (lumped inductance and capacity) is

$$f^2 = \frac{1}{4 \pi^2 L C},$$

we evidently must put

$$L = \frac{2}{\pi} L' \text{ and } C = \frac{2}{\pi} C'$$

if the two frequencies are to be the same:—that is, in so far as determining quarter wave length resonance frequency is concerned, the total inductance L' acts as tho it had only 63.6 per cent. of its actual value, and similarly for the capacity.

SUMMARY: Working at frequencies from 12 to 152 cycles per second, an artificial antenna made up of numerous sections each having lumped capacity and inductance (and closely simulating an actual antenna), is carefully studied. The effective capacity, inductance, and resistance are measured and found to agree with theory; and the theoretical effects of capacity and inductance loading are similarly experimentally verified.

Digitized by Google

DISCUSSION

Dr. A. E. Kennelly (communicated): Professor Morecroft's paper is particularly interesting, as furnishing a new cross-connection between the radio laboratory and the power-transmission laboratory; or between oscillatory phenomena, at perhaps 1,000,000∽, and steady-state phenomena at perhaps 100∽. It shows an ingenious means of deducing what happens in the oscillations of an antenna during a cycle of say a few microseconds, from observations of what happens, in the steady state of standing waves, on a low-frequency artificial line. We have had artificial electric antennas, consisting of a fixed condenser associated with a reactor; but here we have an artificial antenna consisting of a suitably modified artificial power-transmission line. This opens up the prospect of developing a low-frequency multi-section antenna, in which the inductance and capacitance are arranged to correspond, point for point, with that of an imitated actual antenna; so that a study of the electric behavior of the model may reveal the behavior of the high-frequency tower system. The prospect of experimental investigation thus opened up is very fascinating.

There is one difficulty in the design of an artificial multisectional antenna, and that is the insertion of radiation resistance. An actual antenna develops a virtual resistance of radiation R' in addition to its conductor resistance R; so that $I^2 R'$ becomes the radiated power dissipated externally, in addition to the $I^2 R$ of power dissipated within the conductor as heat. It would be very desirable to insert the correct amount and distribution of R' in the artificial antenna, as deduced from the observed behavior with L, C, and R.

Digitized by Google

DISTRIBUTED INDUCTANCE OF VERTICAL GROUNDED ANTENNAS*

By

A. Press

(Assistant Professor of Electrical Engineering, University of Oklahoma)

Formulas have been suggested for estimating the self induction of vertical antennas. Such formulas have moreover been employed in estimating the effect of inductance and capacity on the distribution of stationary waves on wires. The whole theory rests on the tacit assumption that the inductance and capacity are uniformly distributed along the wires in question, which in fact is not the case. In the subjoined paper the inductance distribution of an earthed antenna will be considered and based on the fact that the ether displacement currents, or electrostatic stresses in the medium will be properly indicated by taking two imaged antennas oppositely disposed with respect to an infinitely conducting lamina providing a return for both earth currents.

It will be necessary to postulate such a system of voltages set up at the base O of the antenna that a uniform current distribution is set up in the antenna, flowing in opposite directions with respect to the infinitely conducting lamina or image plane representing the earth's surface. In this way the displacement currents will take paths substantially the same as those usually assumed for a Hertzian oscillator except that the flux lines of displacement on the lower half are imaged with respect to the upper half. That this is nearer approximation to actual conditions should follow from the fact, first, that the image field restricts the actual field to its own domain, and, secondly, that in this way there is not the usual difficulty in calculating inductances of finite open circuited wires where the so-called return wire is assumed to be infinitely removed from the actual vertical antenna under consideration.

* Received by the Editor April 10, 1917.

Digitized by Google

The antenna will therefore be assumed to have impressed upon it an alternating current uniformly distributed thruout the length of the antenna. The magnetic intensity H will be

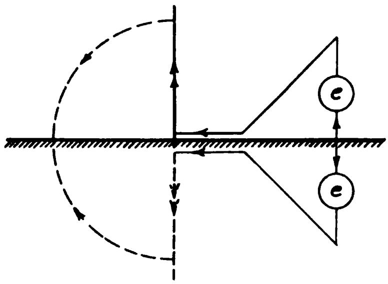


FIGURE 1

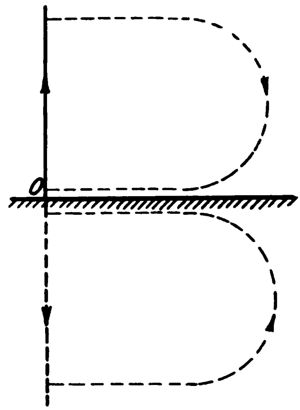


FIGURE 2

considered first for a point P distant r from the antenna axis for a height $\lambda = l + x$ from the image end S of the aerial.

The intensity due to the current element $i\,dx$ at R is

$$H_{dx} = \frac{i}{10}\,dx\,\frac{\sin PRM}{(MP)^2+(MR)^2} = \frac{i\,r\,dx}{10\{(x-\lambda)^2+r^2\}^{\frac{3}{2}}}$$

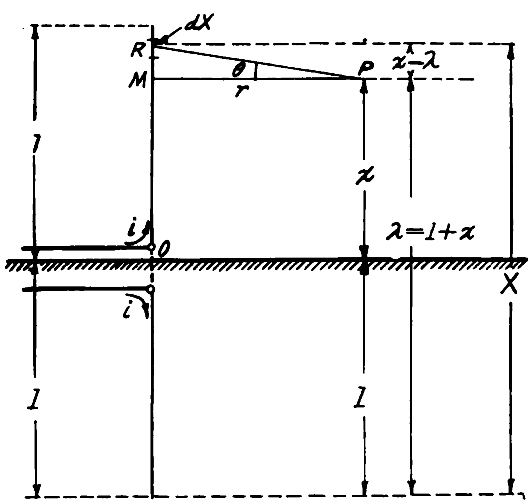


FIGURE 3

Digitized by Google

Thus the intensity H_x at P due to the entire antenna system, which latter includes the image antenna, is

$$H_x = \int_{x=l}^{x=2l} \frac{i\,r\,d\,x}{10\left\{(x-\lambda)^2+r^2\right\}^{\frac{3}{2}}} + \int_{x=0}^{x=l} \frac{-i\,r\,d\,x}{10\left\{(x-\lambda)^2+r^2\right\}^{\frac{3}{2}}}.$$

To integrate the above let

$$x-\lambda = r\tan\theta$$

and then

$$H_x = \frac{i}{10\,r}\left[\frac{2l-\lambda}{\sqrt{(2l-\lambda)^2+r^2}} + \frac{(-\lambda)}{\sqrt{(-\lambda)^2+r^2}} - 2\,\frac{l-\lambda}{\sqrt{(l-\lambda)^2+r^2}}\right].$$

To find the total number of external flux linkages per centimeter at the distance x above the plane of the earth's surface, it will be necessary to find

$$\int_{r=a}^{r=\infty} H_x\,d\,r = \phi_x$$

where a is the radius of the antenna wire. Performing the necessary integrations

$$\phi_x = \frac{1}{10}\log\frac{\left\{(2l-\lambda)+\sqrt{(2l-\lambda)^2+a^2}\right\}\left\{\sqrt{\lambda^2+a^2}-\lambda\right\}}{\left\{(l-\lambda)^2+\sqrt{(l-\lambda)^2+a^2}\right\}^2}$$

Removing the origin of coordinates by referring the points along the antenna to distances x removed from the earth's surface we have $\lambda = l+x$, and therefore

$$\phi_x = \frac{i}{5}\log_\varepsilon\left[\frac{\sqrt{x^2+a^2}+x}{a}\right].$$

The inductance in henrys being defined as the flux per ampere divided by 10^8, we have

$$L_x = 2\,(10)^{-9}\log_\varepsilon\left[\frac{\sqrt{x^2+a^2}+x}{a}\right]$$

or practically

$$L_x = 2\,(10)^{-9}\log e\left(\frac{4\,x}{d}\right).$$

where d is the diameter of the antenna wire. It is easily seen that the inductance at the earthed end of the antenna is zero whereas at the top of the antenna it is the greatest.

SUMMARY: Assuming a uniform current distribution along the antenna, the variation of distributed inductance along the antenna is studied.

Digitized by Google

Appendix

The following may be of value in considering the validity of the foregoing development:

In considering the self induction coefficient of a long transmission line in which the overhead conductor is run parallel to the earth's surface, the self induction coefficient L is considered constant. This amounts to regarding the end effect of the line at the source of e. m. f. as negligible.

In the above consideration the distributed leakage conductance from the line to earth is taken to have no influence on the self induction coefficient as such, tho necessarily the current density in the circuit must always be far from uniform from the source outward. Evidently the self induction coefficient is calculated on the basis that the leakage conduction currents from the source outward along the line as well as the variable condensance current is assumed to have no influence on the self induction coefficient which is calculated on the basis that a uniform or unit ampere of current is flowing along the line.

Whereas the self induction coefficient, therefore, is assumed as independent of leakance or condensance, the *inductance drop* is dependent on the current density from point to point of the line.

Digitized by Google

MUNICIPAL REGULATIONS COVERING RADIO STATIONS*

(A Discussion on "ENGINEERING PRECAUTIONS IN RADIO INSTALLATIONS" by ROBERT H. MARRIOTT)

BY

LIEUTENANT ELLERY W. STONE, U.S.N.R.F.

(DISTRICT COMMUNICATION SUPERINTENDENT, SAN DIEGO, CALIFORNIA)

Mr. Marriott's paper very aptly covers a subject which has been of interest to the writer for the past eight years. While the various phenomena encountered in low voltage circuits caused by the operation of radio transmitters in their vicinity are often capable of explanation, it seems somewhat difficult to predict what will happen in a given case, so that Mr. Marriott's plan of stating the results of individual cases appears to be the best method of approaching the problem of interaction between radio frequency circuits and audio frequency or direct current circuits.

In connection with Mr. Marriott's suggestion that the "Underwriters' Code" be enlarged so as to include within its scope the installation of radio apparatus, the following may be of interest. During the month of December, 1916, the writer was asked by the Electrical Department of the City of Oakland, California, to collaborate in the drawing up of an ordinance to regulate the installation of radio apparatus in that city. It is the custom of most municipalities, upon the recommendation of the civic electrical department, to pass an ordinance adopting the "National Underwriters' Code" as the criterion in the regulation of electrical installations, with such additional provisions as may be considered expedient. In Oakland, for instance, it is required that an electrical installation be made by a registered electrician who is required to deposit a cash bond with the city, and the customary provisions are made for "rough-in"

* Presented before the San Francisco Section of The Institute of Radio Engineers, February 20, 1917. Received by the Editor, March 2, 1917. Mr. Marriott's paper appeared in the "PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS," volume 5, number 1 (February, 1917), page 9.

Digitized by Google

and "final" inspections by city electrical inspectors who hold their positions by local civil service.

After several conferences, the following provisions were decided upon and incorporated in legal form in the proposed ordinance, which, by the time this paper appears in print, will probably be passed.

1. No radio apparatus, whether for receiving or transmitting purposes, connected to an elevated antenna, may be installed within the City of Oakland without a permit from the City Electrical Department.

2. All radio apparatus must be installed subject to the provisions of the "National Underwriters' Code" in force and subject to the following additional provisions:

a. No antenna wires shall be strung over electrical wires whose potential to ground exceeds 250 volts.

b. Every radio station shall be equipped with a lightning switch which shall serve to ground the antenna at all times when the station is not in use and during electrical storms.

c. The wire from the antenna to the lightning switch, commonly known as the lead-in, shall be of such size that its cross-sectional area in circular mils shall not be less than the cross-sectional area of the wire used in the antenna times the number of antenna wires. The current carrying capacity of the lightning switch shall not be less than the accepted current carrying capacity of the "lead-in." The cross-sectional area of the wire from the lightning switch to the earth connection shall not be less than that of the "lead-in."

d. The "lead-in" must be brought thru an approved non-inflammable, non-combustible insulator.

e. The earth connection shall conform to that specified in the "Underwriters' Code."

f. Approved surge protectors, i. e., mica condensers with capacitances not less than 0.5 microfarad, lamps or carbon rods, shall be connected between earth and all electrical wires whose potential to earth exceeds 50 volts.

g. In installations where it is impossible to eliminate surges or antenna induction, the service to the radio station shall be run from a power transformer, the secondary of which is connected to no other lighting or power circuit.

3. The radio installation shall not be supplied with power for operation until same has been approved by the City Elec- Department.

Digitized by Google

4. All high voltage circuits shall be so insulated as to reduce the fire hazard to a minimum.

The reason for the adoption of some of these provisions is obvious, the others will be discussed.

Number 1 was intended to bring all radio experimenters under the jurisdiction of the Electrical Department in order that their activities might be watched. It was considered that the fire hazard from an improperly erected antenna, due to its proximity to high voltage wires or danger from lightning was sufficient justification for requiring a receiving station to be brought within the scope of the ordinance.

While natural electrical phenomena of any violence on the Pacific coast were extremely uncommon a few years ago, several electrical storms have occurred within recent months and the frequency of their occurrence seems to be increasing. This fact is responsible for the adoption of 2 (b). It is doubtful whether the use of a lightning switch, no matter how installed, will completely safeguard a wooden building in the event that an antenna connected thereto be struck by lightning. However, an ungrounded antenna may often be charged to enormous potentials owing to a heavily charged "thunder" cloud or to a lightning discharge occurring in the vicinity, and such charges may be readily dissipated to earth by proper precaution. The writer has witnessed examples of the former phenomenon at his experimental station.

2 (c) was intended to obviate the absurdity of grounding an antenna having a number 18 "lead-in" by a number 4 ground wire and a 100-ampere lightning switch as the 1915 "Underwriters' Code" at present requires.*

The adoption of such an ordinance to regulate radio installations was considered imperative by the Oakland Electrical Department because of the fact that irresponsible experimenters have for many years been raising havoc with lighting circuits, because of surges and antenna induction burning out lamps and appliances connected to such circuits, as set forth in Mr. Marriott's paper. The fire hazard from such practice was actually considered to be greater than that from any other type of electrical installation. That such a state of affairs is reaching a vexing magnitude is shown by the fact that the California Railroad Commission (a state committee for the regulation of public utilities), acting on the petitions of various power companies,

* Diameter of number 18 wire = 0.040 inch = 0.102 cm.
Diameter of number 4 wire = 0.204 inch = 0.520 cm.

Digitized by Google

has recently ruled to the effect that power companies, at their option, may refuse to supply consumers with electricity in the event that radio transmitters are connected to their circuits

The writer has witnessed cases where high potentials have been completely eliminated on the power lines at the radio station by the usual methods, only to lead to breaking down insulation on the same lines several hundred feet away. It would appear that the surge takes the form of a stationary electric wave, that by grounding the line thru protective devices at the radio apparatus, we secure a node of potential, the loop occurring at some point removed from the station.

The subject of stationary electric waves on wires is an interesting one and has been investigated by many physicists. Fleming has developed a set of equations showing that if a simple harmonic E.M.F. is applied at one end of a wire of finite length, the potential at any point on this wire may be obtained by taking the algebraic sum of two potentials, one due to the source at the origin, the other due to an electrical image of this source. The distance from the open end of the wire to the position of the image is equal to the length of the wire. That is to say, there is a wave traveling on the wire from the end at which the periodic E.M.F. is applied, and a wave reflected from the open end of the wire. When the length of the wire bears the proper relation to the frequency of the applied E.M.F., the interference between these two waves causes a resultant series of stationary nodes and loops of potential to be set up, corresponding to the stationary air waves in stopped organ pipes.

If the length of the wire is one fourth of the wave length of the applied E.M.F., the combination of the initial and reflected waves is such as to cause a steady increase of potential following the ordinates of a sine curve, from the origin to the open end of the wire. It may be shown that if the length of the wire is any multiple of a quarter wave length, loops of potential will occur at each quarter wave length along the wire.

A more complete theoretical investigation of this subject has been made by Professor H. M. Macdonald, who finds that the length of the fundamental wave on a wire is more nearly five times the length of the wire. However, for the purpose of this paper, it will be considered sufficiently accurate to note that if any of the various low voltage circuits in the vicinity of the radio station have lengths approximating one-fourth of the transmitting wave length, or multiples thereof, stationary electric waves with potentials of some magnitude will be generated

Digitized by Google

therein. With modern power distribution in cities and customary house wiring, this is a condition not difficult of fulfilment, so that while the induced current set up by a radio transmitter may have a node of potential at the station, where every care has been taken to secure such a node by proper surge protection, the loop of potential may occur at some point removed from the radio installation where no provision has been made to protect the line and the appliances connected thereto. Hence, it is advisable in cities, where the secondary distributing leads of the power systems are often several blocks in length, and from which many consumers are supplied, to place each radio installation on a separate power transformer. The secondary lead may then be a hundred feet or less in length and there will not only be less opportunity for excessive potentials to be built up, but there will be no place where such potentials can cause damage.

There are three ways by which stationary waves may be set up on wires, i. e., by direct, inductive, or static (capacitive) coupling.

Applied to the subject under consideration, direct discharge from the transmitting apparatus is illustrative of the first method of coupling. If the transformer of the radio transmitter be poorly constructed so as to permit actual leakage, high potentials of audio frequency may find their way back on to the line, and if resonance effects in the windings are present, radio frequency potentials may also be present on the line. Such cases as this, however, are rare.

Inductive coupling between radio frequency circuits and low potential circuits is probably the chief cause for most of the surges present on the latter circuits. The primary requisite for this type of coupling is that the circuits, or portions of them, be parallel.

Static coupling is brought about by having the two circuits under discussion in close proximity to each other but not necessarily parallel. The writer had occasion to witness a case where potentials were set up in a lighting circuit by an antenna lead run exactly at right angles to the lighting circuit a few inches away, clearly a case of static coupling.

It would appear that most of the induction of high potentials takes place by virtue of the inductive or static coupling of the antenna circuit with other circuits in its proximity. The writer has never seen a case where induced currents were set up in low potential circuits with the antenna circuit disconnected.

Digitized by Google

Besides the induction of high potentials of radio frequency on low voltage circuits, currents of audio frequency equal to the train frequency of the antenna may be set up as well. The method of their generation is obscure, it may be due to some form of excitation by which an impulse or surge occurs for each train in the antenna circuit, but whatever their source, their presence may be easily detected with a telephone receiver, even without the use of a loose contact or rectifying detector. It is the presence of these audio frequency currents in telephone lines which is responsible for the annoyance caused subscribers by radio transmitters in their vicinity, and since their frequency is of the same order as voice frequency, which is assumed to be 796 in telephone practice, they cannot be drained from the line by condensers having a high, low frequency impedance as in the case of radio frequency currents.

Some years ago, the writer witnessed a curious case of induced surges on a power line. An experimenter had a special power service supplied for his station, being the only consumer on a three kilowatt power transformer, which was wound in the usual 10:1 step-down ratio. Full protection was made for the elimination of induced surges by the usual methods, nevertheless, when the station was in operation, brush and corona discharge appeared on the primary leads of the power company's transformer which finally resulted in setting fire to a tree thru which the primary leads were strung. The theory of resonance effects in an audio frequency transformer, due to the distributed capacitance of multiple layer winding, is probably the correct explanation of the phenomenon, altho it is barely possible that audio frequency potentials or surges, having the same frequency as that of the wave trains in the antenna, were induced in the secondary leads of the power distribution system by the antenna which ran parallel to them, and were stepped up in the power transformer. That the potential was stepped up in the transformer by some method was demonstrated by the fact that no corona existed on the secondary leads from the transformer.

In addition, the writer has observed a case of high potential generation in a lighting circuit such that when the radio transmitter was being operated, lights connected to this circuit would flash up to an alarming brilliancy. Grounded condensers, whose radio frequency impedance was very low, but with high audio frequency impedance, connected to the line in the usual fashion did not serve to ameliorate conditions, whereas a few tungsten lamps connected to earth eliminated the trouble entirely.

Digitized by Google

This would appear to be another proof of the presence of audio frequency impulses or surges.

In this connection, the writer wishes to endorse the use of the metallic filament lamp bank as a surge protector. Its impedance being independent of frequency, if enough lamps are used, it will serve equally well in handling audio or radio frequency surges and is indestructible. As Mr. Marriott points out in his paper, mica or paper condensers are liable to puncture and, when protected by fuses, as they should be, are removed from the circuit without any warning. A small bank of lamps for this purpose may be controlled thru a proper switch or the transmitting key so as not to consume current except when the transmitter is being operated.

In cities where telephone lines are run underground or in aerial lead cable suspension, inductive interference from radio stations is not particularly annoying. Cases arise frequently where trouble is caused by an experimenter grounding his transmitter on the same ground as that used by the telephone, but the remedy for this is obvious. In the event that sparking occurs in the carbon block lightning arrester which will result in fusing the arrester, grounding the line and rendering it inoperative, the telephone company upon request can furnish copper blocks such as are used on toll lines to replace the carbons. However, in localities where the telephone wires are not run in a grounded sheath, very severe interference may take place.

The writer was called upon recently by the Pacific Telephone and Telegraph Company to assist in the elimination of a troublesome case of radio interference caused by a three kilowatt station located on the outskirts of a small town, in which locality none of the telephone wires were run in grounded cable.

Figure 1 is a diagram of the situation. Extremely loud signals of the same frequency as the train frequency or spark frequency of the radio station were received at the exchange board some four miles (6 km.) from the station when the transmitter was operated. A series of experiments were accordingly conducted to see if the interference could be reduced.

Telephone line number 1 served the radio station. Telephone line 2 served a subscriber living two miles past the radio station. Line 3 connected with a small town four miles (6.5 km.) away in a direction at right angles to line 2.

The loudest interference at the exchange was experienced on these three lines altho signals could be heard on other lines as

Digitized by Google

well, due to the fact that all lines into the exchange were brought thru a common cable.

In the belief that the interference was caused by induction from the antenna to that part of line 1 marked AB, the line was opened at A. No effect was noticed.

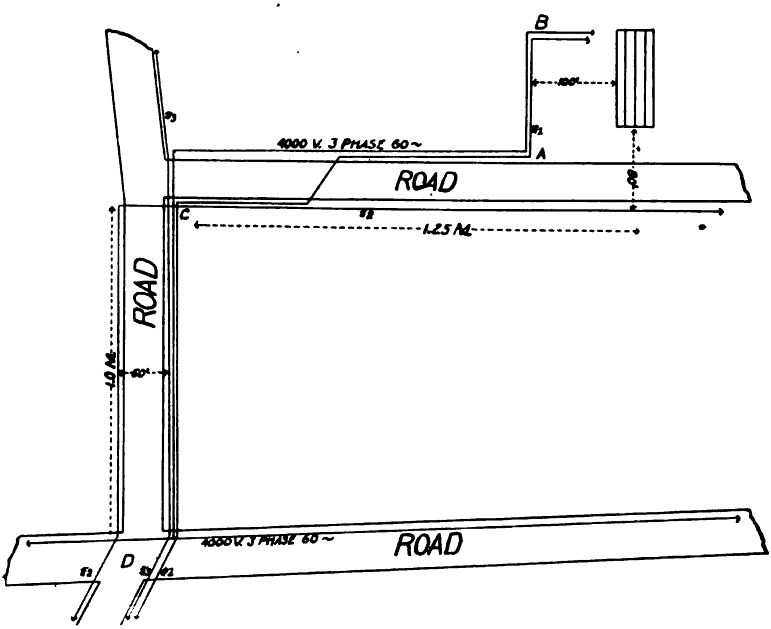


FIGURE 1—Chart Showing Antenna, Power, and Telephone Lines with Induced Interference

Line 1 was next opened at C. This reduced strength of signals on Line 1 at the exchange, all other lines remained the same.

Line 2 was cut at C. Interference was reduced on this line, all other lines remained the same.

Lines 1 and 2 were cut at D. Interference was eliminated on these lines, interference remained the same on Line 3. Line 3 was cut at D, all interference being eliminated.

This had but served to locate the source of trouble: the elimination of the interference with lines 1, 2, and 3 restored to service was another problem.

In telephone practice, it is customary to isolate a "noisy" line, that is to say, a line experiencing moderate interference

Digitized by Google

from power lines or a line with a partial ground, by a repeating coil, as shown in Figure 2. A repeating coil, as it is termed in telephone parlance, is a 1:1 transformer, designed to operate on 796 cycles with a D. C. resistance of 22 ohms in each of its windings.

These were interposed in lines 1, 2, and 3 at *D* and reduced the interference considerably but not entirely.

It is significant that the interference was not eliminated until all lines were opened at *D*, which was the last point at which the telephone lines ran parallel with the power line.

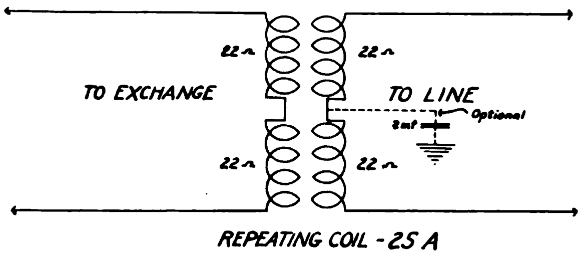


FIGURE 2—Use of Repeating Coil to Isolate "Noisy" Telephone Line

This power line was 4,000 volt, 3 phase, 60 cycle service supplying the ranch on which the radio station was located. Power for the station was obtained from a 20:1 step-down transformer, one leg of the primary of which was connected to earth, the other to one wire of the 3 wire, 3 phase system.

It is obvious that line 3 could receive no induction from the radio antenna directly, nor could lines 1 and 2 when cut at *C*. With line 2 at right angles to the antenna and 80 feet (25 m.) from it at its nearest point, it does not appear that it could receive much interference from the antenna at any time.

With lines 1 and 2 open at *C*, the only source from which 1, 2, and 3 could receive induction was the power line, which parallels all lines for the mile (1.6 km.) from *C* to *D*. Lines 1 and 3 were but 6 feet (2 m.) from the power line over this distance.

Surges in the power line were probably induced by the antenna between the points *A* and *B* and in turn induced in the telephone lines along their entire length. These surges may have been of radio or audio frequency, but whatever their fre-

Digitized by Google

quency, the frequency of the current in the telephone lines was of audio frequency.

For a complete elimination of the interference, such as was obtained by opening all lines at *D*, it was recommended that the telephone wires in lines 1, 2, and 3 be run in a grounded lead sheath or lumped together and surrounded with a frequently grounded "messenger."

In connection with the induction of audio frequency currents in circuits near radio transmitters, it has been the writer's experience that these audio currents are of moderate potential, are only set up within a wire when in extremely close proximity to the exciting circuit, and have the same frequency as the train frequency in that circuit.

Besides the annoyance caused by radio circuits on power circuits the latter may similarly react on the former. Most experimenters have observed the inductive interference caused in their receiving circuits due to alternating current lines in their vicinity. This may be even of such magnitude as to render the reading of weak signals impossible as the writer found it to be in his station. The situation here was as follows. Power for the transmitter was furnished by a 2 wire, 220 volt, 60 cycle service, run in conduit from a special power transformer to the transmitting room, adjoining the receiving room. The lighting service in the building was of the usual 3 wire, 110 volt, 60 cycle, grounded neutral system. By a series of tests, it was found that the interference was caused by the 220 volt circuit, one leg of which was dead-ended in the transmitting apparatus, the other being open thru the transmitting key and controlling switch. By connecting the dead-ended leg to earth, eliminating the possibility of a static charge accumulating on the network of apparatus and connecting wires, the inductive hum was entirely eliminated.

In concluding, the writer wishes to acknowledge his indebtedness to Mr. H. U. Linkins, Division Toll Inspector of the Pacific Telephone and Telegraph Company, for his helpful assistance in the preparation of this discussion.

SUMMARY: The chief features of a proposed municipal code (for the city of Oakland, California), covering all radio stations, are given, together with the basis of each regulation.

The induction of radio and audio frequency surges in power and telephone lines is then considered; and a particularly complex case of both sorts is described in detail. The methods of investigation and elimination of trouble are discussed.

Finally, some methods for the elimination of the hum induced in radio receivers from power lines are described.

Digitized by Google

THE MANUFACTURE OF VACUUM DETECTORS*

By

O. B. Moorhead

(Chief Engineer, Moorhead Laboratories, San Francisco, California)

Altho the majority of radio engineers are familiar with the use and operation of vacuum tube detectors, a brief description of their manufacture may be interesting.

In the early experimental work on this type of device, we strove to produce a detector which would combine maximum operating efficiency with inexpensive manufacture. The next point considered was the production of desirable conditions, i.e.; tubes that possessed oscillating characteristics, tubes that were exceptional detectors, and tubes that displayed both qualities. The third consideration was the production of a device easily handled and shipped without disturbing the adjustment of the elements and damaging the filaments.

Tubes and bulbs of various shapes and sizes were tried using a gaseous medium ranging from one millimeter to 0.025 millimeters of vacuum, many materials being employed as elements. Various exhausts were applied but it was soon found that the employment of a gaseous medium introduced considerable difficulty in the matter of accurate reproduction of a desired result. Gases at pressures ranging from one millimeter to 0.0013 millimeters were next experimented with.

I found that a tube containing a platinum filament in an atmosphere of hydrogen, at pressures comparable with one millimeter, gave fair results. Tungsten filaments were then tried in higher vacua as well as at the so-called "gaseous medium" pressure. It was immediately noticed that conditions could be duplicated as soon as vacua above that which allowed a "gaseous medium" to exist, were obtained. Moreover, tungsten was ideal as a filament not only because of its refractory qualities and low volatility but also because it acts as a purifying agent by attacking any traces of residual gases that may remain in the tube and forming compounds which are then volatilized on the walls of the tubes.

* Received by the Editor, February 15, 1917.

Digitized by Google

As the parts are small and complicated, the glass is worked before the blowpipe, after it has been brought into the form of tubes by the glass works. This tubing is obtained by first blowing a bulb, then fusing an iron rod to a point diametrically opposite the blowpipe and rapidly separating the two points of attachment from each other.

Various grades of glass were experimented with, and a mixture containing a high percentage of lead and a small quantity of silicic acid was found to be the easiest to work and produced a detector of maximum sensitiveness when used in conjunction with the aluminum plate and copper grid. In the selection of the glass to be used, the devitrification of the glass had to be considered, as during exhaustion of the tubes it is necessary to subject them to a temperature near the point of softening and nearly all glasses, when maintained at this temperature for any length of time, have a tendency to separate out into the crystalline state.

There has been considerable discussion regarding the elements in this type of device and I may say that aluminum plates and copper grids were first selected on account of their electro-chemical relation to the tungsten filament. Later, numerous other metals were tried under the same and other conditions of exhaustion and showed widely different operating characteristics.

The selection of metals for the elements is very difficult, as a slight difference in either the copper or aluminum changes the whole system of exhaust. For instance, copper and aluminum purchased from one factory will require a certain degree of applied temperature during the evacuation, while another factory lot of the same weight and size will require an entirely different exhaust.

I have eliminated this variation to some extent by subjecting the aluminum plates to a temperature of approximately 600 degrees Fahrenheit (315° C.), immersing them in a saturated solution of cyanide of potassium, and finally rinsing in alcohol. The copper is subjected to heat until it glows, when it combines with the oxygen of the air to form a black, brittle oxid which breaks off in scales and exposes the underlying metal which is of rose red color. It is then placed in a current of moist air and becomes covered with a layer of oxygen compounds, which remains very thin but closes the pores of the metal.

The exhaustion of the tubes is the most important operation because of the fact that the low vacuum of the round bulb nickel

Digitized by Google

element audion which permits of gas conduction is not used in the tubular "electron relay," wherein all gas phenomena must be eliminated.

To produce the high vacuum necessary, I have found that a Gaede mercury pump capable of producing a vacuum of 0.00001 millimeter, backed by a piston pump, such as the Geryck type, is the most satisfactory method of evacuation.

The manifold to which the tubes to be exhausted are attached and the vacuum line connecting the manifold to the pumps are preferably made of large diameter tubing. A container filled with pentoxid of phosphorus is connected in the vacuum line between the pump and the manifold. The manifold is contained in an oven heated by gas and arranged so that the tubes during exhaustion may be heated to high temperatures.

The lead glass tubing, used as the container for the elements in the tubular type detector, is obtained from the glass works in lengths of 6 feet (2 m.) with an inside diameter of 0.875 inch (2.2 cm.) and a wall of 0.032 inch (0.7 mm.) thickness. This tube is cut in lengths of about 6 inches (15 cm.) and one end is drawn down to a point. Two stems are made of glass tubing similar to those used in an incandescent lamp, one stem contains the grid and two filament leads and the other contains the plate connection and one filament lead. After the wire is sealed into these stems, they must be annealed very carefully. The annealing consists in allowing the temperature to drop very slowly, since quickly cooled glass is subject to internal strains which arise in the following manner: In rapid cooling, a low temperature is soon established at the surface and the outermost layer solidifies while the interior tends to contract, thereby exerting a pressure on the outer layer which is directed inwards. This may cause the stem to crack.

After the stems are annealed, the grid is wound to the proper diameter and the filament is clamped onto the two leads. The plate is mounted on the other stem and the two stems are then connected together by means of the filament. Final adjustment of the plate and grid is then made. The spacing between the elements is not very critical in this type of device, but it is best to wind the grid to a large enough diameter so that it will strike the plate rather than the filament when the tube is jarred.

After adjustment on the plate and grid has been made, the assembly is inserted into the prepared tubes and the end seals made. A short length of small diameter tubing is attached to the seal at one end of the tube, this being for connection to

Digitized by Google

the pump manifold. The tube is then carefully annealed and is ready for exhaustion.

A number of tubes are sealed on the manifold in the oven and the temperature is gradually increased to 900 degrees Fahrenheit (480° C.) at which point the pumps are started. The tubes are heated in this manner before the pumps are started so that the air contained in the tubes may conduct the heat to the central elements and drive off the occluded gases. When the pumps have produced a vacuum of one micron, the temperature of the tubes is very gradually increased to 1000 degrees (540° C.). At this point they must be watched very closely as the melting point of this glass varies greatly and should the walls of the tubes become soft, the vacuum would cause collapse. From one micron, the vacuum slowly increases, and after about five hours of continuous pumping the tubes are sealed off at the manifold and allowed to cool in the oven.

McLeod gauges are used in the measurement of vacua but I have found that a much more accurate vacuum comparison can be made using a large induction coil. For this purpose an electrode is sealed to the manifold or at some point in the vacuum line. One terminal of the coil is connected to this electrode and the other coil terminal is connected to the low vacuum pump. A calibrated spark gap is used on the coil and when the vacuum is high enough and the residual gases are properly pumped from the tube a spark will jump the gap without a glow in the vacuum line or tubes. The vacuum used in the tubular detector will permit a five inch (12.5 cm.) spark between needle points in air.

Prof. Richardson has shown that when new metals are heated to incandescence they emit positive ions, probably because of the impurities or gases in the metal. I have found that this positive discharge must be eliminated to obtain maximum sensitiveness of the tubular detector, and this is accomplished during the manufacturing stage by burning the filament on alternating current for about two hours. Tubes that have not been treated in this manner are found to be less sensitive than those in which the positive ionization has been destroyed.

SUMMARY: Experiments with three-electrode vacuum detectors are described. Various filament, grid and plate metals were tested. Different degrees of exhaustion were used.

The paper then describes in detail the manufacture of a tubular detector and the testing thereof.

Digitized by Google

DISCUSSION

H. R. Sprado: Referring to your last paragraph regarding the emission of positive ions, I gather that this phenomena is rather transient. If a tube is left idle for quite a period of time, would it recover the positive ionization?

O. B. Moorhead: The phenomena referred to I have noticed to be an emission from fresh wires only, and when these wires are heated in a vacuum the positive ionization decays rapidly at first and then more slowly until it finally disappears. This rapid disappearance can be facilitated by applying a positive potential to the hot metals. I do not know if it will re-appear when left absolutely idle but it can be revived by burning a fresh wire near it, the old wire being cold. This must be due to a substance which is distilled from one metal to another.

H. R. Sprado: In some research work that I have recently done with the "gaseous medium" type of device, I have noticed that this power of emitting positive ions can be restored if the plate or filament end of the audion is held to one terminal of a high tension coil and a luminous discharge be caused to fill the bulb.

Do you believe that this rapid decaying of the positive ionic emission bears any relation to that phenomenon commonly called "photo-electric fatigue"?

O. B. Moorhead: It probably does, as photo-electric sensitiveness is not recovered after the surface has rested. Have you ever tried your luminous glow experiment on a plate that shows photo-electric fatigue and ascertained if it regains its sensitiveness?

H. R. Sprado: No, I have not. I note that you have experimented with platinum filaments in hydrogen. Did you make any experiments with tungsten in the same or other gases?

O. B. Moorhead: I have found that tungsten in hydrogen operates very poorly and that exceedingly small amounts of gas cause very great changes in the values of the constants. This applies to all the gases with which I have experimented.

H. R. Sprado: While making the above experiments I had occasion to use different pressures of argon in your tube. I found that the saturation currents in this gas have the same values as in the higher vacua. I noted that, when small quantities

Digitized by Google

of argon were used the attainment of saturation was greatly facilitated because of the action of positive ions formed by impact ionization, in reducing the effect of the mutual repulsion of the electrons. When argon was present in greater quantities, the saturation current was considerably higher. Have you any theory regarding this increase in current?

O. B. Moorhead: I presume this was due to ionization by collision of the electrons with the argon gas molecules.

Digitized by Google

ON THE PHENOMENA IN RESONANCE TRANSFORMER CIRCUITS*

By

HIDETSUGU YAGI

(PROFESSOR IN THE COLLEGE OF ENGINERING, TOHOKU IMPERIAL UNIVERSITY, SENDAI, JAPAN)

About three years ago, while staying in Germany, I was engaged in the study of the phenomena in resonance transformer circuits. Prof. H. Barkhausen of the Technische Hochschule (Institute of Technology) in Dresden was so kind as to give me valuable suggestions and to permit me to experiment in the Institut für Schwachstrom Technik (Division of Feeble Current Engineering) of the above named college.

In June, 1914, I submitted to him a manuscript with dozens of oscillograms verifying the results of an analytical solution, which was nearly ready for publication. Owing to the sudden outbreak of war, the publication was unfortunately suspended, and much of the material rendered unavailable.

There had previously been an excellent paper by M. Blondel,[1] in which he pointed out the necessity for taking the spark discharge of the condenser into consideration. Many papers have since been published treating the same problem under the same conditions. Among recent publications are, as far as I know, those of Mr. Weinberger[2], Mr. Bouchardon[3] and Mr. Cutting[4]. The chief omission in these studies seems to me to be that they do not properly treat the superposition of the transients produced by the successive discharges.

Since it is not possible for me to secure the experimental data, I shall communicate here, as a further discussion of this problem, only the theoretical part of the investigation on the basis of my recollections. As the purpose is not to give any exact mathematical expressions but to make clear the complex phenomena by plain representations, and since cumbersome

---

* Received by the Editor, January 13, 1917.

[1] A. Blondel, "L'Eclairage Electrique," **18,** 1907, May 25, and June 8, or "Journal de Physique," **7,** (Serie 4), 1908, p. 89.

[2] J. Weinberger, "Proc. I. R. E." Dec., 1915.

[3] V. Bouchardon, "Lumière Electrique," **33,** 1916, April 29, and May 6.

[4] F. Cutting, "Proc. I. R. E.," April, 1916.

Digitized by Google

expressions seem rather likely to obscure mental images, the treatment is made as easy as possible and every permissible approximation is introduced. Nevertheless, I hope the deduction will prove interesting in throwing more light on the method of solving the problem.

The Transient Phenomenon

Let us neglect R_1 the effect of which can as well be studied by considering R_2. This obviously makes the solution much simpler.

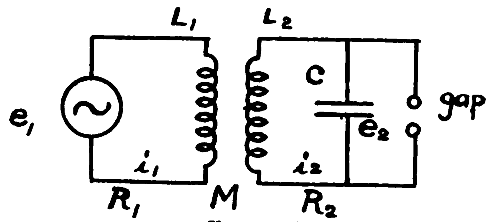


Figure 1

It is well known that the secondary current i_2 and the condenser potential e_2 can be expressed, for the non-sparking condition, by:

$$i_2 = I_2 \sin(\omega t + \phi_2) \tag{1}$$

$$e_2 = -\frac{I_2}{\omega C} \cos(\omega t + \phi_2) \tag{2}$$

Suppose that the spark gap is so adjusted that the condenser discharges at the potential E_o. An instantaneous discharge of the condenser across the gap is equivalent to the superposition of a transient equivalent to that which would occur if the condenser C, charged to an equal and opposite potential $-E_o$, discharged back from the secondary thru the transformer to the primary, assuming no source of E. M. F. in the primary. (Figure 2.)

This transient can be obtained neglecting R_1, from the equations:

$$\left.\begin{aligned} L_1\frac{di_1}{dt} + M\frac{di_2}{dt} &= 0 \\ R_2 i_2 + L_2\frac{di_2}{dt} + M\frac{di_1}{dt} + \int\frac{i_2}{C}dt &= 0 \end{aligned}\right\} \tag{3}$$

and the solution is, as well known,

$$i_2 = A\,\varepsilon^{-\alpha t} \sin(\beta t + \gamma) \tag{4}$$

Digitized by Google

and $$e_2 = \int \frac{i_2}{C} dt \tag{5}$$

where $$\alpha = \frac{L_1 R_2}{2(L_1 L_2 - M^2)} \tag{6}$$

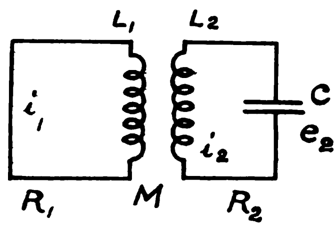


FIGURE 2

$$\beta = \sqrt{\frac{L_1}{C(L_1 L_2 - M^2)} - \frac{L_1^2 R_2^2}{4(L_1 L_2 - M^2)^2}} \tag{7}$$

A and γ are integration constants.

When $t = 0$, $\quad i_2 = 0$

and $\quad e_2 = E_o$

therefore $$i_2 = -\frac{\alpha^2 + \beta^2}{\beta} C E_o \varepsilon^{-\alpha t} \sin \beta t \tag{8}$$

and the condenser potential dies away according to the equation:

$$e_2 = \frac{\sqrt{\alpha^2 + \beta^2}}{\beta} E_o \varepsilon^{-\alpha t} \cos\left(\beta t - \tan^{-1}\frac{\alpha}{\beta}\right) \tag{9}$$

Neglecting α in comparison with β, we have approximately

$$i_2 = -\beta C E_o \varepsilon^{-\alpha t} \sin \beta t \tag{8'}$$

and $$e_2 = E_o \varepsilon^{-\alpha t} \cos \beta t \tag{9'}$$

We will consider the two most important forms of regular sparking, which we will call:

(I) Alternate discharge—one spark per half cycle.

(II) Unidirectional discharge—one spark per cycle.

(I) Alternate Discharge

Under steady sparking condition, the condenser potential between two consecutive discharges will be made up of a

Digitized by Google

sinusoidal sustained oscillation and an infinite number of transient oscillations, i. e.,

$$e_2 = E_c \sin(\omega t + \phi) - E_o \varepsilon^{-at} \cos \beta t + E_o \varepsilon^{-a\left(t+\frac{\pi}{\omega}\right)} \cos \beta\left(t + \frac{\pi}{\omega}\right)$$

$$- E_o \varepsilon^{-a\left(t+\frac{2\pi}{\omega}\right)} \cos \beta\left(t + \frac{2\pi}{\omega}\right) + E_o \varepsilon^{-a\left(t+\frac{3\pi}{\omega}\right)} \cos \beta\left(t + \frac{3\pi}{\omega}\right) - \cdots$$

$$= E_c \sin(\omega t + \phi) - \sum_{n=0}^{n=\infty} (-1)^n E_o \varepsilon^{-a\left(t+\frac{n\pi}{\omega}\right)} \cos \beta\left(t + \frac{n\pi}{\omega}\right) \quad (10)$$

The first term is what was already given in (2) as

$$-\frac{I_2}{\omega C} \cos(\omega t + \phi_2)$$

and the second term, the infinite series, is absolutely convergent and becomes

$$\sum_{n=0}^{n=\infty} (-1)^n E_o \varepsilon^{-a\left(t+\frac{n\pi}{\omega}\right)} \cos \beta\left(t + \frac{n\pi}{\omega}\right) = K E_o \varepsilon^{-at} \cos(\beta t - \theta) \quad (11)$$

where

$$K = \frac{1}{\sqrt{1 + 2\left(\varepsilon^{-a\frac{\pi}{\omega}}\right) \cos \beta \frac{\pi}{\omega} + \left(\varepsilon^{-a\frac{\pi}{\omega}}\right)^2}}$$

$$= P_o(x) - r P_1(x) + r^2 P_2(x) - \cdots \quad (12)$$

and

$$\tan \theta = \frac{\varepsilon^{-a\frac{\pi}{\omega}} \sin \beta \frac{\pi}{\omega}}{1 + \varepsilon^{-a\frac{\pi}{\omega}} \cos \beta \frac{\pi}{\omega}} \quad (13)$$

in which

$$x = \cos \beta \frac{\pi}{\omega}$$

$$r = \varepsilon^{-a\frac{\pi}{\omega}}$$

and $P_o(x), P_1(x), \cdots$ zonal harmonics.

Thus $$e_2 = E_c \sin(\omega t + \phi) - K E_o \varepsilon^{-at} \cos(\beta t - \theta) \quad (14)$$

(II) Unidirectional Discharge

Similarly, for the unidirectional discharge,

$$e_2 = E_c \sin(\omega t + \phi) - \sum_{n=0}^{n=\infty} E_o \varepsilon^{-a\left(t+\frac{2n\pi}{\omega}\right)} \cos \beta\left(t + \frac{2n\pi}{\omega}\right) \quad (15)$$

Digitized by Google

or $$e_2 = E_c \sin(\omega t + \phi) - K E_o \varepsilon^{-a t} \cos(\beta t + \theta) \tag{16}$$
where

$$K = \frac{1}{\sqrt{1 - 2\left(\varepsilon^{-a\frac{2\pi}{\omega}}\right) \cos \beta \frac{2\pi}{\omega} + \left(\varepsilon^{-a\frac{2\pi}{\omega}}\right)^2}}$$

$$= P_o(x) + r P_1(x) + r^2 P_2(x) + \cdots \tag{17}$$

and $$\tan \theta = \frac{\varepsilon^{-a\frac{2\pi}{\omega}} \sin \beta \frac{2\pi}{\omega}}{1 - \varepsilon^{-a\frac{2\pi}{\omega}} \cos \beta \frac{2\pi}{\omega}} \tag{18}$$

in which

$$x = \cos \beta \frac{2\pi}{\omega}$$

$$r = \varepsilon^{-a\frac{2\pi}{\omega}}$$

and $P_o(x)$, $P_1(x)$, $\cdots$ zonal harmonics.

The Factor K

Thus in both alternate and unidirectional discharges, the variations of e_2 can be represented by the superposition of a sustained oscillation of the forced frequency and a damped occillation of the natural frequency of the circuit. K is an important factor which comes in whenever one treats of the superposition of periodic transient phenomena. For its calculation, the series of spherical harmonics (12) or (17) is convenient when $r \left(= \varepsilon^{-a\frac{\pi}{\omega}} \text{ or } \varepsilon^{-a\frac{2\pi}{\omega}}\right)$ is comparatively small. In our present case r is not much smaller than unity, as $\frac{\pi}{\omega}$ is extremely small, and the series form of K is not convenient. Figure 3 and Figure 4 show the values of K and $\frac{1}{K}$ when r is assumed equal to unity.

In Figure 4 the broken lines represent the curves of K and $\frac{1}{K}$ for $\varepsilon^{-a\frac{2\pi}{\omega}} = \frac{1}{\varepsilon}$, or $a\frac{2\pi}{\omega} = 1$; i.e., when the damping factor is extremely large.

Terminal Conditions

There are two conditions which we desire to have fulfilled from the practical point of view; namely: the rise of e_2 before

Digitized by Google

a discharge should be steep, or $\left(\frac{d\,e_2}{d\,t}\right)_{t=\frac{\pi}{\omega}}$ be large in order that the discharge takes place sharply at a definite phase, and the rise of e_2 after a discharge should be slow, or $\left(\frac{d\,e_2}{d\,t}\right)_{t=0}$ be

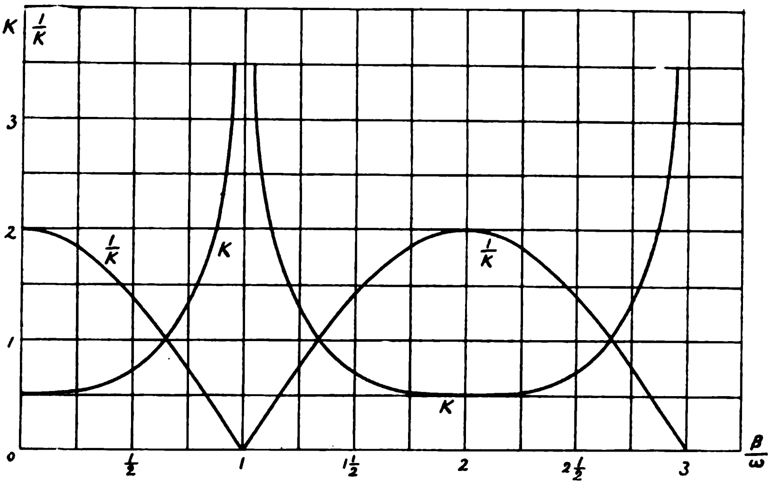


FIGURE 3—Alternate Discharge

small in order that the ionization of the gap is sufficiently reduced before e_2 begins to rise from zero, so that no extra spark may take place.

These two conditions are theoretically inconsistent, because, since what is effected in the circuit by a discharge is nothing but the superposition of a transient of (8′) or (9′), $\frac{d\,e_2}{d\,t}$ will be equal just before and after the discharge, i. e.,

$$\left(\frac{d\,e_2}{d\,t}\right)_{t=0} = -\left(\frac{d\,e_2}{d\,t}\right)_{t=\frac{\pi}{\omega}} \qquad \text{for alternate discharge}$$

and

$$\left(\frac{d\,e_2}{d\,t}\right)_{t=0} = \left(\frac{d\,e_2}{d\,t}\right)_{t=\frac{2\pi}{\omega}} \qquad \text{for unidirectional discharge.}$$

The equations (8′) and (9′) are approximate results and the phase angle $tan^{-1}\frac{\alpha}{\beta}$ was also neglected. It may seem that this term might cause some change of $\frac{d\,e_2}{d\,t}$ before and after the

Digitized by Google

discharge; however, its effect can never be very large, and it is almost out of the question to attempt to make the two above-mentioned conditions consistent simply by means of the proper selection of damping. On the other hand, these conditions can and must evidently be adjusted by the proper choice of the ratio $\frac{\beta}{\omega}$.

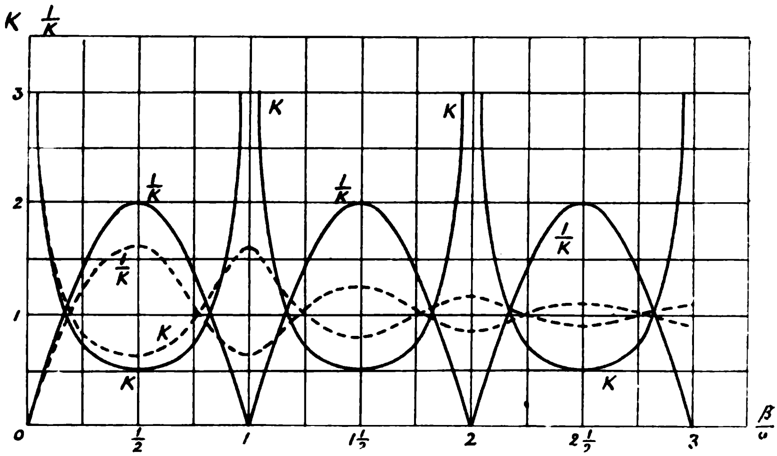


FIGURE 4—Unidirectional Discharge

Now at

$$\left.\begin{array}{r} t=0, \quad e_2=0 \\ \dfrac{d e_2}{d t} \geqq 0 \end{array}\right\} \quad \text{and} \tag{19}$$

Another terminal condition is:

at $t=\frac{\pi}{\omega}$, $e_2=-E_o$ and $\frac{d e_2}{d t} \leqq 0$ } for alternate discharge,

and at $t=\frac{2\pi}{\omega}$, $e_2=E_o$ and $\frac{d e_2}{d t} \geqq 0$ } for unidirectional discharge.

Possible Range of Steady Sparking

So far, we have assumed the discharge potential E_o to be arbitrary and independent of E_c; but, in order that the as-

Digitized by Google

sumed steady sparking state may be possible, E_o ought to have a certain relation to E_c.

One of the limiting conditions is, as shown,

$$\left(\frac{d e_2}{d t}\right)_{t=0} \geqq 0.$$

The other limiting condition is that the absolute value of e_2 must never reach E_o before the assumed moment of discharge. In other words, the maximum values $e_{2,max}$ of Figure 8 must always be smaller than E_o, or,

$$|e_{2,max}| < E_o$$

(I) For alternate discharge, the first limit of $\frac{E_c}{E_o}$ is determined as follows:

From (14)

$$\left(\frac{d e_2}{d t}\right)_{t=0} = \omega E_c \cos\phi + \sqrt{a^2+\beta^2}\, K E_o \sin\left(\tan^{-1}\frac{a}{\beta} - \theta\right) \qquad (20)$$

hence the limiting condition $\left(\frac{d e_2}{d t}\right)_{t=0} = 0$ becomes approximately

$$\omega E_c \cos\phi - \beta K E_o \sin\theta = 0. \qquad (21)$$

By (19) and (14)

$$(e_2)_{t=0} = E_c \sin\phi - K E_o \cos\theta = 0 \qquad (22)$$

Eliminating ϕ from (21) and (22)

$$\frac{E_c}{E_o} = K\sqrt{\cos^2\theta + \left(\frac{\beta}{\omega}\right)^2 \sin^2\theta}$$

Substituting the values of K, $\sin\theta$, and $\cos\theta$,

$$\frac{E_c}{E_o} = \frac{\sqrt{\left(1+\varepsilon^{-a\frac{\pi}{\omega}}\cos\frac{\beta}{\omega}\pi\right)^2 + \left(\frac{\beta}{\omega}\right)^2\left(\varepsilon^{-a\frac{\pi}{\omega}}\sin\frac{\beta}{\omega}\pi\right)^2}}{\left(1+\varepsilon^{-a\frac{\pi}{\omega}}\cos\frac{\beta}{\omega}\pi\right)^2 + \left(\varepsilon^{-a\frac{\pi}{\omega}}\sin\frac{\beta}{\omega}\pi\right)^2} \qquad (23)$$

To determine the other limit of $\frac{E_c}{E_o}$, put $\frac{d e_2}{d t} = 0$, or

$$\omega E_c \cos(\omega t + \phi) + \sqrt{a^2+\beta^2}\, K E_o \varepsilon^{-a t} \sin\left(\beta t - \theta + \tan^{-1}\frac{a}{\beta}\right) = 0,$$

solve for t which gives the time t_o corresponding to $e_{2,max}$ and substituting t_o for t of the expression (14) and putting $|e_{2,max}| < E_o$ the required ratio $\frac{E_c}{E_o}$ can be obtained.

Digitized by Google

As this process of solution is difficult, several curves with various $\frac{E_c}{E_o}$ have been plotted for different $\frac{\beta}{\omega}$ and the critical values of $\frac{E_c}{E_o}$ determined, beyond which the assumed regular sparking becomes impossible.

(II) For unidirectional discharge, the first limit is similarly determined by

$$\frac{E_c}{E_o}=\frac{\sqrt{\left(1-\varepsilon^{-a\frac{2\pi}{\omega}}\cos\beta\frac{2\pi}{\omega}\right)^2+\left(\frac{\beta}{\omega}\right)^2\left(\varepsilon^{-a\frac{2\pi}{\omega}}\sin\beta\frac{2\pi}{\omega}\right)^2}}{\left(1-\varepsilon^{-a\frac{2\pi}{\omega}}\cos\beta\frac{2\pi}{\omega}\right)^2+\left(\varepsilon^{-a\frac{2\pi}{\omega}}\sin\beta\frac{2\pi}{\omega}\right)^2} \qquad (24)$$

and the other can be deduced by the process similar to that for the alternate discharge.

Figure 5 gives the possible range of the regular alternate discharge and Figure 6 the same for the regular unidirectional discharge.

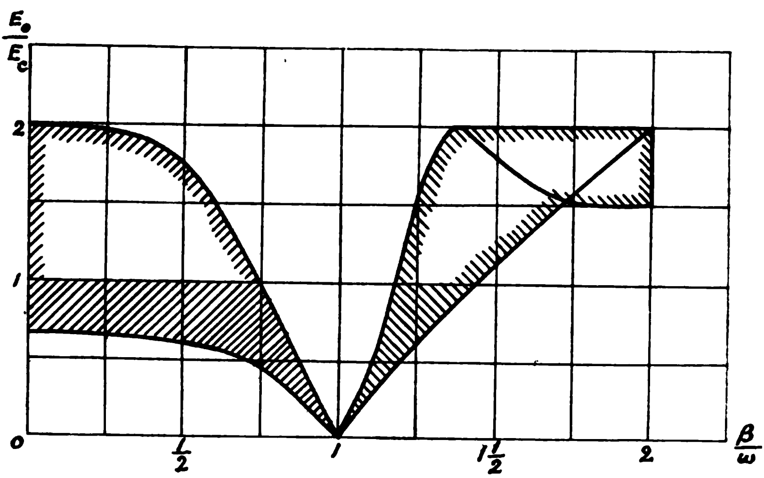


FIGURE 5—Alternate Discharge

In calculating these diagrams $\varepsilon^{-a\frac{\pi}{\omega}}$ and $\varepsilon^{-a\frac{2\pi}{\omega}}$ have been assumed equal to unity for the sake of simplicity.

Unless the value of $\frac{E_o}{E_c}$ corresponding to a certain value of $\frac{\beta}{\omega}$ lies within the shaded area of the figures, the presupposed sorts

Digitized by Google

of regular sparking are impossible. It is especially noticeable that there is no possible range at the absolute resonance $\frac{\beta}{\omega}=1$. How wide the possible range at resonance would actually be if $\varepsilon^{-\alpha\frac{\pi}{\omega}}$ or $\varepsilon^{-\alpha\frac{2\pi}{\omega}}$ were not equal to unity and $tan^{-1}\frac{\alpha}{\beta}$ of the equation (9) were taken into account, is another problem which seems worthy of a further study.

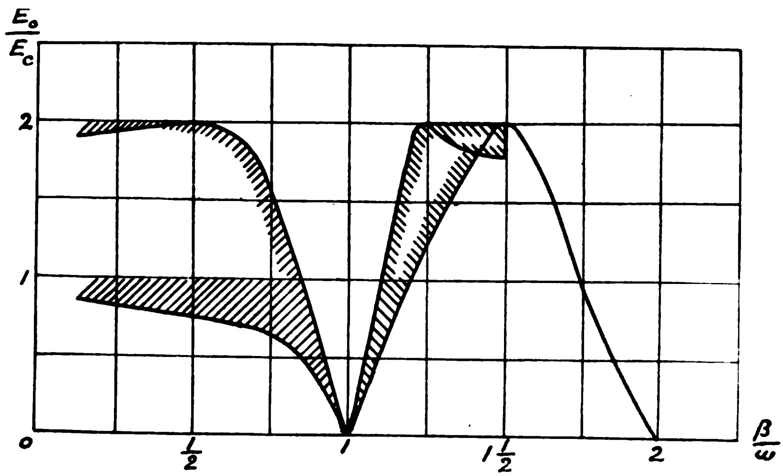


Figure 6—Unidirectional Discharge

Whatever be the theoretical conclusion as above deduced, there is no doubt that $\frac{\beta}{\omega}$ must not be too far from the resonance value, because otherwise the power factor of the supply circuit will become very small and the net output of the system will be much reduced. By this consideration, there should be a certain optimum condition off resonance, but not very far removed therefrom.

Unless the initial spark starts spontaneously or is effected by some special means, the condenser will never discharge when E_o is adjusted above E_c; that is to say, for $\frac{E_o}{E_c}$ larger than unity, certain devices must be provided for starting the initial spark. Or else the possible range becomes restricted to that portion of the shaded area in Figure 5 and Figure 6 that lies below the line $\frac{E_o}{E_c}=1$. Then it may be said that there is a little wider range

of possible operation for $\frac{\beta}{\omega} < 1$ than for $\frac{\beta}{\omega} > 1$. Moreover when β is larger than ω there is a greater tendency torward partial discharges. Experiment also shows that the operation is usually much steadier when the natural frequency of the circuit β is smaller than the forced frequency ω.

E_c is not a constant but varies as indicated by an ordinary resonance curve, so that the discharge potential E_o must be within the shaded area of Figure 7.

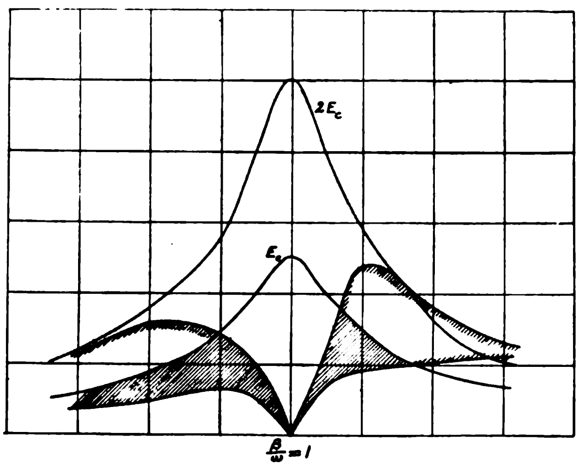


FIGURE 7

CURRENT CURVES

So, as long as the number of discharge is not more than one per half cycle, the discharge occurs after the maximum crest of the current curve. The charge corresponding to the area $B-A$ or $G-F+D$ raises the condenser potential to E_o. As e_2 must never reach E_o before the moment of discharge,

$$B > 2A$$

$$F > 2D$$

and
$$G > 2(F-D)$$

which can be easily checked by the actual oscillograms.

Mr. Weinberger[1] and also Mr. Bouchardon[2] have assumed that the discharge takes place at the maximum of the potential wave, or at the moment of zero charging current. This is

[1] *Loc. cit.*
[2] *Loc. cit.*

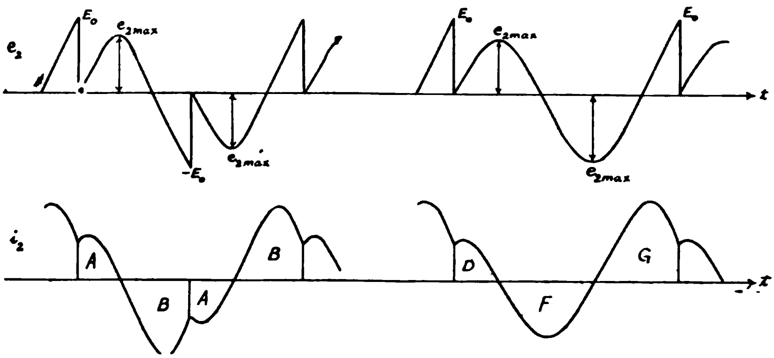
Digitized by Google

actually not the case and it seems rather impossible to have a discharge exactly at the maximum of the voltage wave.

In the case of partial discharges, Figure 9, (two or more discharges per half cycle), we have the relation

$$P - S = Q = R$$

which determines the time intervals between consecutive discharges.



Alternate Discharge   Unidirectional Discharge

FIGURE 8

It is obvious that there is a direct current component of i_2 in the case of unidirectional discharges. This D. C. component is likely to magnetize the iron core asymmetrically. If, consequently, the potential wave becomes asymmetrical, then the tendency for unidirectional discharge will possibly be augmented. It was noticed in experiments that the unidirectional discharge was the one that could persist with the utmost steadiness.

Concluding Remarks

The above calculations have been carried out only for two particular states of regular sparking and it must be remembered that there are an indefinite number of steady sparking states, ranging between rare spark operation with each discharge at an interval of several cycles and partial discharges of many sparks per half cycle, and the two cases treated in this paper are only the particular cases best suited for tone production.

There are other states of sparking which very much resemble those treated in this paper. One of them is that in which the sparking occurs nearly once per cycle or once per half cycle, but

Digitized by Google

the period of sparking is very slightly smaller than $\frac{\pi}{\omega}$ or $\frac{2\pi}{\omega}$, and there is one extra spark in several cycles. In the other case the period is very slightly larger than $\frac{\pi}{\omega}$ or $\frac{2\pi}{\omega}$ and the discharge will miss once per several cycles. The matter depends upon whether the energy supply is slightly more or less than the loss of energy by the regular discharge of the condenser at E_o.

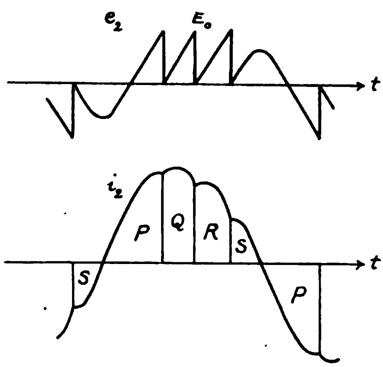


FIGURE 9—Fractional Discharge

It is not easy to distinguish these states of discharges from truly regular sparking, especially when the discrepancy is inconsiderable, altho Mr. Cutting says in answer to Prof. Morecroft's discussion that he could hear the missing of one spark in a regular sparking state.

The author once observed the change of the oscillographic images of regular sparking at 50 cycles per second, when the discharge gap was kept constant (E_o) and the resonant condition of the circuit was varied gradually from one side to the other of resonance by varying the series inductance in the primary.

It was hardly possible to observe any change in the regular sparking in passing thru absolute resonance. The conclusion that there is no range for regular sparking at resonance is based on the assumption of the ideal regular sparking and of $\varepsilon^{-a\frac{\pi}{\omega}} = 1$. Therefore it seems to be premature to say that absolute resonance is impracticable or that it is a point of minimum output. Mr. Cutting's calculation is based also on the assumption of the ideally regular sparking state and it is a different question whether the watt output would actually show a minimum when

Digitized by Google

the condition is altered thru resonance with "practically" regular sparking.

It is another question whether the apparently regular sparking, tho not truly regular, produces less musical sounds in the receiving telephone than the ideally regular sparking on both sides of resonance.

The above gives but one theoretical reason, from the point of view of tone production, against operation at absolute resonance, but it must not be looked upon as conclusive.

SUMMARY: After reviewing some of the previous work in connection with the superposition of the recurrent transients of regular spark discharge of a condenser, the author develops the solutions for the cases of one and two sparks per cycle. The solutions are then studied in detail with particular reference to the possibility of operating such transformer systems at the absolute resonance point, a possibility hitherto denied. The conditions under which steady sparking may occur are also considered.

Digitized by Google

FURTHER DISCUSSION ON "THE COUPLED CIRCUIT BY THE METHOD OF GENERALIZED ANGULAR VELOCITIES" BY V. BUSH

By

JOHN R. CARSON

(AMERICAN TELEGRAPH AND TELEPHONE COMPANY, NEW YORK)

Professor Bush's interesting paper appearing in the October issue of the "PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS" is accompanied by an appendix giving a "Summary of Wagner's Proof of Heaviside's Formula." This proof contains several fallacies which, curiously enough, are mutually destructive, so that the final formula is correct. The fallacies are, however, serious from a mathematical standpoint, and I therefore take this opportunity to point them out. It is a curious coincidence that Malcolm's proof, referred to in a footnote on page 377, is likewise vitiated by balancing fallacies of much the same character. I might add that, inasmuch as I have not consulted Wagner's original paper, my criticisms are directed against the proof, as given by Professor Bush, only.

Professor Bush states that the infinite integral

$$f(t) = \frac{E}{2\pi j}\int_{-j\infty}^{j\infty} \frac{\varepsilon^{nt}}{n}\, dn \tag{1}$$

defines a function which is zero for negative values of t and E for positive values of t. That this is incorrect is easily shown as follows: Change t to $-t$ in (1), and we get

$$f(t) = \frac{E}{2\pi j}\int_{-j\infty}^{j\infty} \frac{\varepsilon^{nt}}{n}\, dn$$
$$= \frac{E}{2\pi j}\int_{+j\infty}^{-j\infty} \frac{\varepsilon^{nt}}{n}\, dn$$

and finally

$$f(-t) = -\frac{E}{2\pi j}\int_{-j\infty}^{j\infty} \frac{\varepsilon^{nt}}{n}\, dn$$
$$= -f(t)$$

This shows that the function defined by (1) has the same absolute

Digitized by Google

value for positive and negative values of t but suffers a reversal of sign at $t=0$.

As a matter of fact the function defined by (1) is equal to $-\frac{E}{2}$ for $t<0$ and $+\frac{E}{2}$ for $t>0$. This may be readily shown in a number of ways; perhaps the easiest is to deduce it from the known value of the function

$$\frac{2}{\pi}\int_0^\infty \frac{sin\,(n\,t)}{n}\,d\,n$$

which is equal to -1 for $t<0$ and $+1$ for $t>0$.

Professor Bush's discussion of the contour integral by which he arrives at the conclusion that the function defined by (1) is 0 for $t<0$ and E for $t>0$, is defective in that it ignores the fact that the pole (0) cuts the path of integration. When this happens no general rule can be laid down as regards the evaluation of the residue since the pole is symmetrical with respect to the two contours of integration. It may be shown, however, that for the function under consideration, ½ the residue is to be included in each contour so that $f\,(t) = \frac{1}{2}E$ for $t>0$

$$f\,(t) = -\tfrac{1}{2}E \text{ for } t<0.$$

This same failure to evaluate properly the residue corresponding to the pole (0) accounts for the final formula (11) which is correct when the applied voltage is 0 for $t<0$ and E for $t>0$, but is incorrect when $f(t)$ is defined by (1). The correct formula in this case is, corresponding to (11),

$$i=\frac{1}{2}\frac{E}{z\,(0)}+\sum_{n_r}\frac{E}{\left(\frac{d\,z}{dn}\right)_{n_r}}\,\varepsilon^{n_r t},\ t>0$$

$$i=-\frac{1}{2}\frac{E}{z\,(0)} \quad \text{for } t<0.$$

Clearly this is the correct solution when we remember that

$$f\,(t)=\tfrac{1}{2}\,E,\ t>0$$

$$f\,(t)=-\tfrac{1}{2}\,E,\ t<0$$

The errors into which this proof falls seems to be due in part to the ambiguity which arises when the path of integration cuts one or more poles of the function. When this happens the evaluation of the residues is almost always a matter of doubt and should be justified by other methods and other considerations if possible. I would suggest in this connection that there is less chance of error if we start with the *current* expressed as

Digitized by Google

a Fourier's integral; thus, corresponding to an impressed force $f(t)$, the resultant current, is

$$i=\int_{-\infty}^{\infty} f(\lambda)\ .\ d\lambda \int_{-j\infty}^{j\infty} \frac{\varepsilon^{n(t-\lambda)}}{z(n)}\, d n .$$

I might mention here that in the September issue of the "Physical Review," I developed and proved from dynamical considerations a general expansion theorem which holds explicity when the impressed force is an exponential function of time, and implicity for functions of arbitrary form. It is there shown that if the impressed force is $E\,\varepsilon^{pt}$, the resultant current (adopting Professor Bush's notation) is given by:—

$$i=\frac{E\,\varepsilon^{pt}}{z(p)}-E\sum_r \frac{\varepsilon^{n_r t}}{(p-n_r)\left(\dfrac{dz}{dn}\right)_{n_r}} .$$

This expression degenerates into the Heaviside formula when p is put equal to zero. It enables us also to evaluate directly the transients when the impressed forces are damped or undamped sinusoidal time functions.

Digitized by Google

Digitized by Google

INDEX TO VOLUME 5

1917

All references to any individual, company, or radio station are fully listed in the index. Answers to points brought out in the Discussions will be listed under the name of the questioner. With the exception of the names of companies, all topics will be listed in general under the *noun* referred to. The numbers correspond to pages in the text. The following abbreviations are used: r. f.—radio frequency; a. f.—audio frequency; l. v.—low voltage; h. v.—high voltage.

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

VOLUME 5 JUNE, 1917 NUMBER 3

PROCEEDINGS
of
The Institute of Radio Engineers

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

PUBLISHED EVERY TWO MONTHS BY
THE INSTITUTE OF RADIO ENGINEERS
ONE HUNDRED AND ELEVEN BROADWAY NEW YORK

Subscription $6.00 per Annum in the United States
$6.60 in all other Countries

GENERAL INFORMATION AND SUBSCRIPTION RATES ON PAGE 170

Entered as second-class matter at the Post-Office, New York

Digitized by Google

Digitized by Google

AT LAST!

A DEPENDABLE AND ECONOMICAL

STORAGE BATTERY

FOR

ELECTRON RELAYS

EDISON STORAGE BATTERY
Type WI-T

SMALL **LIGHT** **RUGGED**

Uninjured by protracted periods of idleness
Easily and quickly recharged
Will give excellent service for many years

RADIO TELEGRAPHIC AND TELEPHONIC LABORATORY
AND EXPERIMENTAL STATION OF
THE COLLEGE OF THE CITY OF NEW YORK

ALFRED N. GOLDSMITH
DIRECTOR

June 4, 1917

DR. MILLER R. HUTCHISON,
Orange, N. J.

My dear Dr. Hutchison:

As I stated to you in our correspondence some time ago, steady sources of potential at voltages between thirty and three hundred have been much required recently in connection with the plate circuit of audions, pliotrons, and other forms of "repeaters" or oscillators of the three electrode vacuum tube type. The requirements are strict, inasmuch as the potential must be constant, there must be no "commutator ripple" to interfere with the reception of faint signals, and the equipment must be compact, comparatively inexpensive, and easy to maintain.

We have had several sets of the "W" batteries in this laboratory for several months and have used them for the purposes mentioned. They seem highly satisfactory and convenient.

Very truly yours,

ALFRED N. GOLDSMITH

Address

Miller Reese Hutchison, Inc.

Distributors of Edison Storage Batteries for Wireless and Emergency Lighting

Orange, N. J.

Digitized by Google

The Standard Instruments
for use on
Wireless Telegraph Panels

Weston

Switchboard Indicating Instruments

Comprise Wattmeters, Frequency Meters, Ammeters and Voltmeters of 7-inch diameter.

In serviceability, durability, accuracy and efficiency these instruments practically attain perfection. They have been universally standardized for wireless service because they have demonstrated that they can be depended upon in any emergency.

Write for detailed information

Weston Electrical Instrument Co.
73 Weston Ave., Newark, N. J.
23 Branch Offices in the Larger Cities

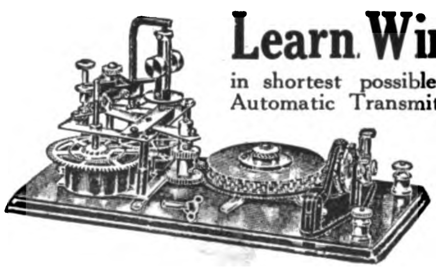
CUTTING & WASHINGTON, Inc.

Commercial Radio Apparatus

For Land and Ship Stations

26 PORTLAND STREET, CAMBRIDGE, MASS.

Learn Wireless at Home



in shortest possible **time with the Omnigraph** Automatic Transmitter. **Connected with Buzzer will send messages, at any speed, just as an expert operator would. Used by U. S. Bureau of Navigation to test all applicants applying for Radio licenses. 2 models. Prices $14 and $20.**

OMNIGRAPH MFG. CO., 39 B Cortlandt St., New York

Digitized by Google

WIRELESS AND EMERGENCY LIGHTING SYSTEMS

When the generator of the ship has been impaired or destroyed and the wireless operator turns to storage batteries for the necessary power, those batteries must be dependable and instantly ready to perform their work.

The "Exide" BATTERY

has repeatedly proved its superiority and has an envious record of achievement in this service. It is used by the U. S. Navy and 36 Steamship Companies for this purpose.

"Exide" Batteries are made by the oldest and largest manufacturer of storage batteries in the country.

Batteries manufactured by this company are used almost exclusively by the large Central Light & Power Companies; in U. S. Submarines, for Wireless and Gun Firing, by Marconi Wireless, in Electric Vehicles, Mine Locomotives, Railway Signals and Independent Lighting Plants.

THE ELECTRIC STORAGE BATTERY CO.

New York Boston PHILADELPHIA, PA. Chicago Denver St. Louis Cleveland Atlanta 1888-1917 Rochester Detroit Toronto Minneapolis Washington Pittsburgh San Francisco Kansas City

MICA CONDENSERS

For Radio Transmitters and Protective Devices, as per Government Specifications

Dubilier Condenser Co., Inc.

217 Centre Street New York City

Digitized by Google

Radio Frequency Instruments

The Roller-Smith Company offers a most complete line of instruments of various types for radio frequency work. The list is as follows:

Radio frequency ammeters, all capacities, switchboard and portable types.

Galvanometer for wave meter and decremeter sets.

Low frequency alternating current ammeters, voltmeters, wattmeters, etc., all capacities, switchboard and portable types.

Direct current ammeters and voltmeters, all capacities, switchboard and portable types.

In spite of present abnormal conditions, we are prepared to make good deliveries.

CORRESPONDENCE IS INVITED

Roller-Smith Company

CHICAGO — Monadnock Block | 233 Broadway, New York — Factory: Bethlehem, Pa. | CLEVELAND — Williamson Building

INTENSIFYING TRANSFORMER

Constructed especially for intensifying in-coming signals.

It can be used for intensifying signals received from any crystal detector by employing it between two detectors. The signals will then be intensified from 10 to 25 times.

As many as three of these transformers can be connected between detectors in cascade, forming an intensifier, making it possible to read signals at present not heard with any single known detector.

No modern wireless station is complete without an intensifier, as when it is needed it is wanted very, very much, so why not provide beforehand?

An intensifier makes possible the use of loose coupling, thus eliminating part of static and other atmospherics. The wireless engineer or operator alone knows the vast interference caused by these unknown phenomena.

Diagram of connections complete with full directions accompanying each instrument

List No. 224 Intensifying Transformer. Price............$15.00

NEW POCKET CATALOG OF ELECTRICAL SUPPLIES ready June 15, 248 Pages. Send for one.

MANHATTAN ELECTRICAL SUPPLY CO., Inc.

NEW YORK—17 Park Place 110 W. 42d St. 127 W. 125th St.
CHICAGO 114 So. 5th Av. ST. LOUIS 1106 Pine St. SAN FRANCISCO 604 Mission St.

Wireless expert at all our stores

Digitized by Google

THE IMPORTANCE OF RADIO COMMUNICATION IS GREATER THAN EVER BEFORE

The increase in ship and shore stations far exceeds what was anticipated by even the most optimistic. Apparatus is being improved and modified continuously. The radio engineer *must* keep in touch with the trend of the art.

In the pages of the

Proceedings of The Institute of Radio Engineers

will be found papers by the radio engineers of almost every country, giving the latest and best methods and the most recent and valuable discoveries.

The PROCEEDINGS is almost always out of print within a few months after publication. Prompt subscription is essential. Subscription rates on page 384 of this issue. Address subscription to the Secretary, Institute of Radio Engineers, 111 Broadway, New York, N. Y.

UNIVERSAL WAVEMETER

TYPE 105D

RANGE 150—11,000 METERS

Price, $133.00

GENERAL RADIO COMPANY

CAMBRIDGE, MASS.

Digitized by Google

DeForest "Oscillion"
(Oscillating-Audion)

Type "S" Laboratory Panel
$60.00

Generator of absolutely undamped oscillations of any frequency. Permits Radio Telephone speech surpassing in clearness that over any wire. For Laboratory and Research Work has a field utterly unfilled. Patents issued and pending.

Prices and particulars from

DeForest Radio Telephone & Telegraph Co.
1391 Sedgwick Avenue, New York, N. Y.

At Last!

Electromagnetic waves of any length from an incandescent lamp

Murdock
Moulded Condensers

Compact, strong and efficient transmitting units worth a trial by every radio engineer. Now in successful operation in many government and commercial stations. Made for commercial use in sections of .002 mfd.

Wm. J. Murdock Company

70 Carter Street **Chelsea, Mass.**

Digitized by Google

C. BRANDES
INCORPORATED

32 Union Square - - New York

MAKERS OF

RADIO HEADSETS

We solicit inquiries from manufacturers of radio apparatus

BAKELITE-DILECTO
The Standard Insulating Material for all

RADIO WORK

Waterproof—Strong—High Electrically—Furnished in Sheets, Rods, Tubes, and Special Shapes. Samples on request.
Also makers of High-Grade Vulcanized Fibre.

THE CONTINENTAL FIBRE CO. - - NEWARK, DEL.

New York Office, 233 Broadway Chicago Office, 332 South Michigan Ave.
Pittsburgh Office, 316 Fourth Ave.
San Francisco Office, 525 Market St.
Los Angeles Office, 411 South Main St.

Kilbourne & Clark Manufacturing Company

Seattle, Washington, U. S. A.

Manufacturers of

RADIO TELEGRAPH APPARATUS

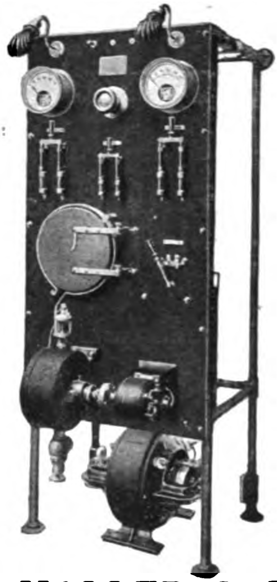
For Commercial, Ship and Shore Stations

AMERICAN TRANSFORMERS
CUSTOM MADE

Designed and constructed to fill the special requirements of our customers
Sixteen years' experience in handling Radio problems

American Transformer Company
143 Miller Street Newark, N. J.

Digitized by Google



HALCUN

Privately Owned

Commercial and Marine Wireless

is giving

Exceptional Service on

Fifty-two Steamers

and

Thirteen Land Stations

Complete Sets from ½ K.W. to 25 K.W.

HALLER CUNNINGHAM ELEC. CO.

SAN FRANCISCO, CAL.

Radio Generators

High frequency alternating-current and high-voltage direct-current radio generators for all purposes.

Crocker-Wheeler Company

Ampere, N. J.

Concentration is the Keynote ~~S~~uccess

THE thousands of users of electric equipment for radio work read many periodicals; but more of them read THE PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS than any other scientific publication.

The Advertising Manager of the Institute (111 Broadway, New York City) will be pleased to give you information concerning

...tisements That Hit the Bull's Eye

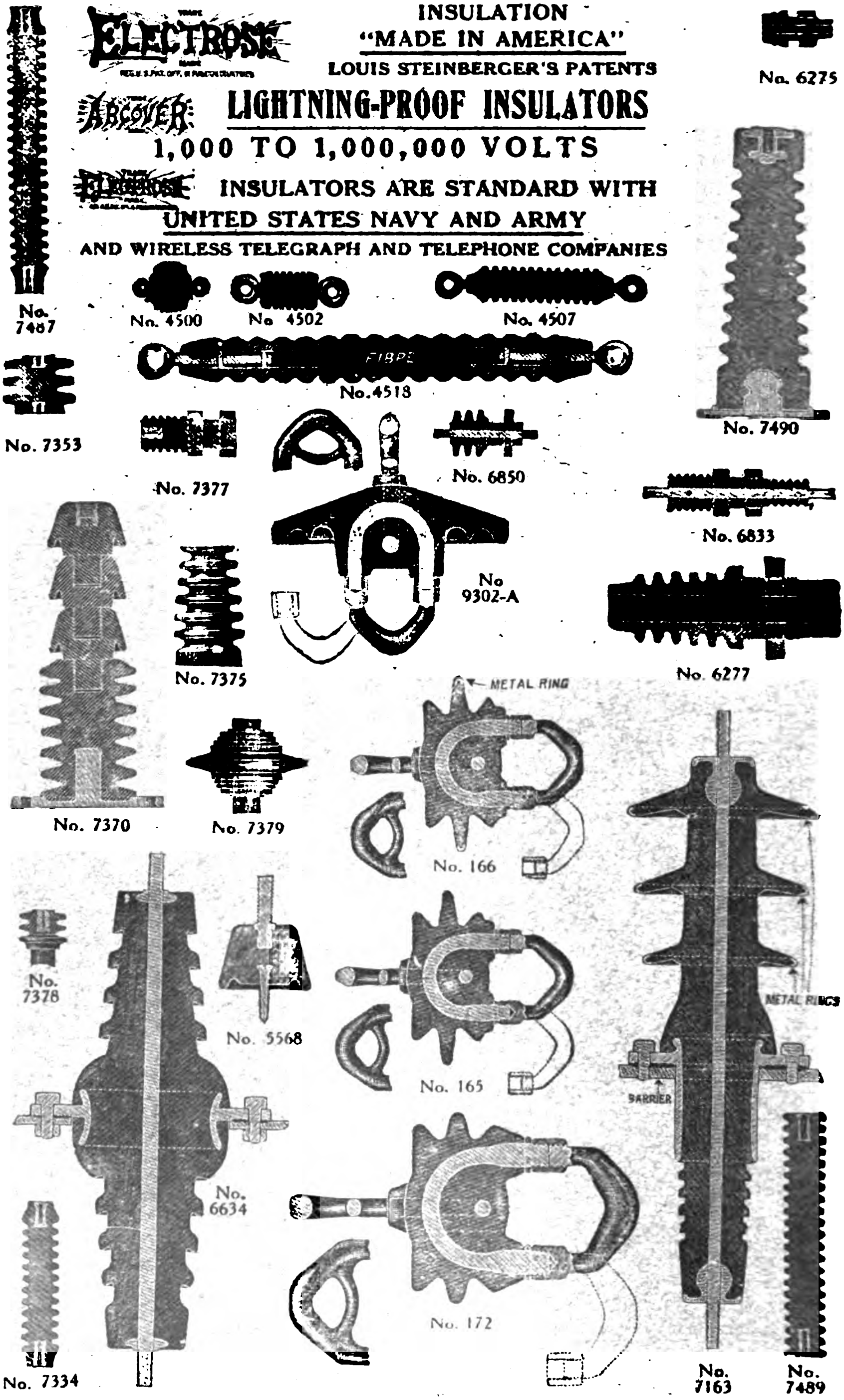
Digitized by Google

ELECTROSE
REG. U.S. PAT. OFF. & FOREIGN COUNTRIES

INSULATION
"MADE IN AMERICA"
LOUIS STEINBERGER'S PATENTS

ARCOVER LIGHTNING-PROOF INSULATORS
1,000 TO 1,000,000 VOLTS

ELECTROSE INSULATORS ARE STANDARD WITH
UNITED STATES NAVY AND ARMY
AND WIRELESS TELEGRAPH AND TELEPHONE COMPANIES



SOLE MANUFACTURERS
ELECTROSE MFG. CO.

66-82 Washington St. 27-37 York St.
66-76 Front St. 1-23 Flint St.
Brooklyn, N. Y., America

BLANCHARD PRESS, N. Y.

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google